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Institute and Related Activities

Heating of Railway Motors in Service and on Test-Floor Runs

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Review of the Subject.—*The rating given to a motor is the manufacturer's guarantee of the motor performance under the conditions given on the name plate.*

Assuming that this rating is entirely safe, then the successful functioning of the motor depends entirely upon the application engineer's analysis of the particular duty that the motor will be required to perform.

Where the required motor output is practically constant the application is simple; however, in many cases the motor load is apt to be anything but constant, consisting of loads of all degrees of magnitude, and in such cases the economically correct application is especially difficult. The past improvements made in the motor design, mechanically and electrically, have resulted in greater importance of the motor-operating temperatures, in fact in the great majority of cases the motor rating is limited only by the motor temperature. It is obvious then that correct motor applications depend to a very great extent upon correct operating temperatures.

Ratings such as the continuous, short-time, normal, and duty-cycle ratings give the performance of the motors under some particular conditions; however, the duty required of a great number of industrial and railway motors will not agree with any of the above ratings. Thus the application of motors to cranes, hoists, steel mills, and railways must be made with the knowledge of the motor's performance under one or more arbitrary conditions.

In general the two ratings which should be known for motor application to such irregular duty are the continuous and a short-time rating. The time period of the short-time rating should not exceed one hour and in many cases a one-half hour run is preferable.

The correct application of a motor requires a knowledge of the thermal conditions inside of the motor. Thus it is evident that the motor must be able to dissipate eventually all of the heat losses generated. On a continuous load the final rate at which the heat is transferred from the motor to the air will be equal to the rate of heat generation.

The resulting temperature rise can be estimated with the physical conditions known. This is simply a problem in physics and involves the conditions of ventilation with the corresponding ventilating surfaces. To predetermine the internal temperatures requires a knowledge of the rate of heat flow along the various heat flow paths to the ventilating surfaces.

Under irregular loads the temperatures are transient and are determined not only by the conditions of ventilation and rates of heat flow, but also by the motor's ability to store heat, which is proportional to the product of the motor's mass and specific heat. Hence the temperature rise of any part of a motor under any given load for some definite time is a function of the rate of heat flow from that part to the surrounding air and its thermal capacity. Thus from the known physical conditions the temperature rise of the motor can be predetermined and with certain assumptions a simple equation can be developed which will give an approximate value of the motor temperature under any given load conditions.

When the constants of the theoretical equations are based upon tests (such as given by short-time and continuous rating) the above method of temperature predetermination will be sufficiently accurate for most practical purposes, and will make possible the calculation of the motor temperature rise under any duty cycle.

The temperatures referred to are not only those temperatures obtained by thermometers upon the surfaces of the machines, but also the maximum internal temperatures, since it is the latter temperatures which first produce insulation failure.

The temperatures obtained by thermometers bear no fixed relation to the maximum temperatures for all types of machines under various loads.

In order to have something concrete to work upon the writer has taken up the heating and cooling characteristics of railway motors. A brief analysis of the heating at the standard ratings is given. The fundamental equations defining the temperature rise of a motor on a continuous or short-time load are developed, and finally the applications of these equations are made in several specific examples.

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The adoption of standard motor ratings for various types of service has greatly facilitated the correct application of the motors. However, the motor's performance can be relied upon only in those applications where the duty required of the motor is equivalent to that specified by the motor's rating. This introduces a factor of uncertainty in the application of the motor to such irregular and intermittent service as is required of crane, hoist, steel mill, and railway motors.

The selection of a proper motor for a particular railway service is without doubt one of the most difficult problems in motor application. For instance the street car motor is subject to daily rush hour loads; to possible heavy peak loads due to a steep track grade; and in addition to this it is called upon to deliver abnormal overloads resulting from conditions such as holiday crowds, trailer operation, snow or the necessity of pulling in a disabled car, and these conditions are apt to be accompanied by a low line voltage.

Railway motor failures may be classed as mechanical and electrical. A large part of the electrical failures is due either to poor commutation and flashing or to excessive temperatures. In the modern commutating-pole motor mechanical failures and those electrical ones which are caused by poor commutation have been greatly reduced; however, the possibility of breakdown due to high operating temperatures is still present. The modern high-speed, ventilated, commutating-pole motor will deliver a much greater output per pound of motor than the early types of railway

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motors. This means of course that the motor's capacity for the storage of heat on short-time overloads has been reduced and has resulted in making the peak load temperatures the predominating factor in some railway motor applications.

The purpose of this paper is primarily to discuss the heating of railway motors on the standard test floor runs and to develop a general method by which the heating can be predetermined for any given service. However, the analysis of the heating problem as given is general, and is applicable to the temperature predetermination of any rotating electric machine.

Standard Motor Ratings

The adoption of a simple test or combination of tests which would be a criterion of a motor's performance in any railway service has been recognized as impractical. With such intermittent loads the best general method of rating should be based upon the motor's overload or thermal capacity and upon its continuous rating. Thus the Standards of the American Institute of Electrical Engineers say that the nominal rating of a railway motor is that output which the motor will develop for one hour with a temperature rise by thermometer at the end of the run of not over 90 deg. cent. on the commutator, and 75 deg. cent. at any other normally accessible part. With this short-time run a majority of the heat losses is stored up in the motor so that this rating is to a certain degree a measure of the thermal capacity of the machine as a unit.

The continuous rating is defined as the input in amperes at which it may be operated continuously at ½, ¾ and full voltage respectively without exceeding a temperature rise of 65 deg. cent. by thermometer (85 deg. cent. by resistance) for Class A[1] insulation and 80 deg. cent. by thermometer (105 deg. cent. by resistance) for Class B[2] insulation.

Thus the continuous rating is a measure of the motor's ability to dissipate heat.

Distribution and Disposal of Heat Losses

With regard to ventilation there are three general classes of railway motors, namely, totally enclosed, self-ventilated and separately ventilated motors. The Institute Standards define a "totally enclosed" motor as one so enclosed as to prevent circulation of air between the inside and the outside of the case, but not sufficiently to be termed "air-tight." A "self-ventilated" machine is one in which the ventilating air is circulated through the machine by a fan, blower or centrifugal device integral with the machine. A "separately ventilated" machine has its ventilating air supplied by an independent fan or blower external to the machine.

1. Class A insulation is composed of specially treated cotton, silk, paper or similar materials.

2. Class B insulation is composed of material capable of resisting high temperatures such as mica and asbestos.

Nominal One-Hour Rating

Table I gives the distribution of losses on four typical types of motors at the one-hour and the continuous rating. This nominal rating is purely an arbitrary one. As previously mentioned the rating

TABLE I.
DISTRIBUTION AND DISPOSAL OF LOSSES IN RAILWAY MOTORS

Type of Ventilation	Enclosed		Self Ventilated				Separate Vent*	
Rating—Time	1 hr.	Cont	1 hr.	Cont	1 hr.	Cont	1 hr.	Cont
Volts	600	450	600	450	600	450	600	450
H. P.	60	..	65	..	25	..	200	..
Amperes	88	36	95	60	37	35	280	220
Rev. per min.	700	827	700	638	1225	950	670	550
Weight of bare motor	2350	..	2350	..	870	..	5200	..
Weight armature	615	..	615	..	225	..	1700	..
Armature watts loss:								
Armature copper	1800	301	2100	840	820	733	3980	2450
Armature iron and stray power	1170	560	1170	620	780	500	3250	2500
One-half friction and windage	300	400	325	280	220	155	900	700
Brush loss	264	108	285	180	111	105	840	660
Total armature loss	3534	1369	3880	1920	1931	1493	8970	5310
Field copper loss	1825	306	2360	950	650	580	4690	2900
One-half friction and windage	300	400	325	280	220	155	900	700
Total motor loss	5659	2075	6565	3150	2801	2228	14560	8910
Per cent copper loss	64.0	29.2	67.9	56.8	52.5	59.0	59.5	60.0
Armature loss per cent of total	62.3	66.0	59.1	61.0	69.0	67.0	61.6	59.5
Watts loss/lb. of motor	2.41	0.88	2.79	1.34	3.22	2.56	2.80	1.71
Armature loss/lb. of armature	5.75	2.22	6.31	3.12	8.68	6.65	5.28	3.13
Armature copper loss/lb. copper	26.5	4.4	30.9	12.3	36.4	32.6	14.7	9.1
Field copper loss/lb. copper	7.1	1.9	9.1	3.7	9.1	8.1	8.7	5.4
Disposal of losses:								
Per cent absorbed	81.4	0	81.9	0	57.5	0	69.0	0
Per cent dissipated from frame	10.8	100	4.6	62.0	12.5	45.0	4.9	14.3
Per cent carried away by the ventilation air through motor	7.8	0	13.5	38.0	30.0	55.0	26.1	85.7

*Separate ventilation on the continuous rating only.

is intended to be a standard of measurement of a motor's thermal capacity. The requirement for this is that no heat loss shall be dissipated from the motor, that is all of the losses must be stored in the motor masses. This condition is approximated in totally enclosed machines where the heat losses from the external frame by radiation and convection rarely exceed 10 per cent of the total loss.

In the early non-commutating-pole motors it was necessary to observe carefully commutation during this one-hour run and this necessitated the removal of the commutator cover. This practise is still used in the modern motors. In fact Rule No. 5202 of the Standards of the A. I. E. E. says that the covers should be arranged to secure maximum ventilation without external blower.

Some of the self-ventilated motors will circulate as much as 50 per cent more air with all covers off than with covers on as in service. This has resulted, as

shown later, in the nominal rating being dependent upon ventilation as well as the thermal capacity of the motor. The table shows that of the total losses, from 59.1 to 69.0 per cent is found in the armature. Since the armature weight is only about one-third of the total motor, its thermal capacity (ability to store heat) on short-time loads will be less than that of the motor as a unit. It results in an armature loss per pound of armature of 5.28 to 8.58 watts. The armature copper loss per pound of copper ranges from 14.7 to 36.4 watts. A loss of 4.5 watts per pound of armature will raise its temperature 75 deg. cent. in one hour if all the loss is stored in the iron and copper. Hence in the 25-h. p. high-speed motor at least $(8.58 - 4.5)/8.58$ or 48 per cent of the total armature loss must be transferred elsewhere; with the larger motors this percentage is considerably reduced. A loss of 3.75 watts per pound of copper if all stored in the metal will raise its temperature 75 deg. cent. in one hour. This means that toward the end of the one-hour run with this motor by far the greater part of the heat loss generated in the armature copper must be transferred to the iron or air and but little of that loss is stored.

On the one-hour run the motor losses are stored up in the iron and copper, carried away by the ventilating air through the motor and dissipated from the external frame by radiation and convection. Table I shows that of the total loss about 81 per cent is stored in the motor parts for the first two motors while for the last two more highly ventilated motors this percentage is 57.5 and 69. This shows that the one-hour rating is not a true indication of the motor's thermal capacity, since the percentage of the heat loss stored in the motor during this run is a function of the motor's ventilation.

Continuous Rating

On continuous duty all of the heat losses in the motor must be transferred to the surrounding air, that is, this rating is not affected by the heat storage capacity of the motor. In a totally enclosed motor the total losses are transferred to the frame and are then liberated by radiation and convection. The frame temperature rise is approximately proportional to the watts per square inch to be liberated. The heat dissipated from the frame is about 0.013 watt per square inch of surface per deg. cent. rise. This is an average value from many tests. The surface is taken as that of a solid cylinder whose over-all dimensions are equal to those of the motor. The actual effective surface is greater than this due to the roughness of the castings and the numerous irregular projections. This accounts for the high value of this constant since the heat loss from a smooth surface due to natural convection and radiation is only about one-half of the above value. With a car speed of 10 mi. per hr. the above constant is approximately doubled. The internal temperature drop from the armature to the frame is a function of the ventilating surface and the internal ventilation. It is evident that the external ventilation on the frame can not affect this internal drop. The external frame rise on continuous duty averages about 60 per cent of the internal temperature rise when measured on the test floor by thermometers. The rating on an enclosed motor is limited by this low heat flow from the frame and by the temperature gradient necessary to cause the armature loss to be transmitted to the internal air and then from this air to the inner frame surface. For continuous-rated enclosed motors the weight per h. p. increases with the motor size. This may be seen for example by the fact that by doubling the motor's dimensions the external ventilating surface is increased to four times its first value while the weight is increased to eight times the original weight.

Ventilated Motors

When air is circulated through a motor by either an internal or external fan the effect is two-fold. It reduces the internal air temperature and for a given loss it decreases the temperature gradient between the ventilating surface and the internal air. It is possible to reduce this temperature drop to a very small value with separate ventilation; however, the internal insulation drop is still present. This temperature difference between the copper and the ventilating surface is the limitation to the degree of ventilation economically possible. Thus Table I shows that the small 25-h. p. self-ventilated motor on the continuous run can dissipate 2.56 watts per pound of motor while the heavy locomotive motor (insulated for 1500 volts) with separate ventilation can get rid of only 1.71 watts on the basis of the same copper temperature rise. This is due to the large internal temperature drop in the windings and insulation of the larger motor which is independent of ventilation. The first two motors listed in the table give a comparison of continuous rating possible on a totally enclosed and a self-ventilated motor of the same weight. It shows that for the same internal temperature rise the enclosed motor can dissipate a loss of 2075 watts while the self-ventilated motor can dissipate 3150 watts. This difference will increase with the speed of the armature.

Application of Motor

The usual method of applying a railway motor to any given service is to estimate the average root-mean-square current from the conditions known. The motor must have a continuous rating at least equal to this r. m. s. current. With this rating known the average operating temperature rise can be estimated from the above current. Due to the irregularity of the load it is necessary to see if the motor has sufficient overload or thermal capacity to take the peak loads without excessive temperature rise. This predetermination of temperature rise on intermittent duty is a very difficult

problem, for which a rigid mathematical solution is practically impossible. However, a comparatively simple approximate solution is possible.

Solution of Problem[3]

The following solution of this problem has been made on the assumption that the heat losses and ventilation in the motor or any part thereof considered are uniformly distributed. This s not strictly correct; practically however it is permissible since the heat losses will to a certain degree distribute themse ves by conduction through the iron and copper.

(5) Total energy loss = stored energy + dissipated energy.

The solution of this equation is given in the appendix. The final equations are:

$$t = 2.3\, t_1 \log_{10} \frac{T_c - T_s}{T_c - T_t} \qquad (10)$$

or an equivalent form:

$$T_t = T_c - (T_c - T_s)\, e^{-t/t_1} \qquad (11)$$

where (e) is the Naperian base (2.718)

t = Time in hours the load is applied.

T_s = Temperature rise at start, deg. cent.

T_t = Temperature rise at end of time (t).

[4]T_c = Final temperature rise on continuous duty, and

$$T_c = \frac{W}{S_e\, r\, K_e + \dfrac{V\, S_i K_i}{V + 0.9\, S_i K_i}} \qquad (8)$$

W = Watts loss of motor or part considered.

S_e = External surface of motor frame in sq. in. This may be figured by considering the motor as a solid cylinder.

K_e = Heat dissipation from the external surface in watts/sq. in/deg. cent = 0.013 approximately when frame is stationary.

r = Ratio of external frame rise to the internal surface rise. This ratio is a function of the degree of ventilation of the motor. On enclosed motors it averages about 0.60; on self-ventilated motors 0.40; and with separately ventilated motors 0.20 to 0.30.

V = Volume of air passing through the motor in cu. ft./min.

S_i = Internal ventilating surfaces of the motor which come in contact with the ventilating air, sq. in.

K_i = Heat transfer from the ventilating surface to the air in watts/sq. in. of surface/deg. cent. difference between the surface and adjacent air. This is determined by the air velocity, direction of air flow with respect to the surface, and the nature of the surface. Fig. 1 shows the curve of an average value for this constant which was obtained from many tests made upon actual machines and experimental apparatus.

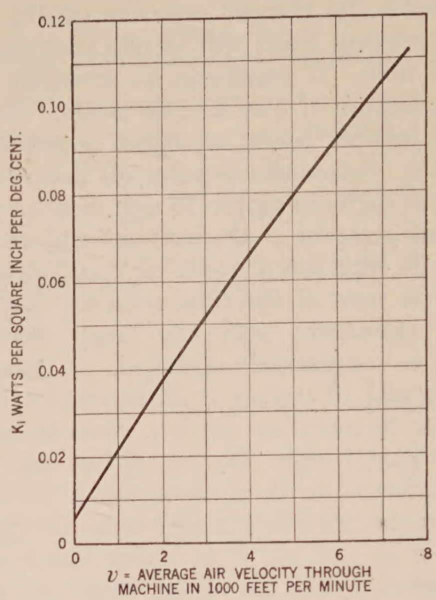


Fig. 1—Surface Heat Dissipation

In watts per sq. in. of surface per deg. cent. difference between surface and air temperature.

It is incorrect to use the above equation (8) for self-ventilated motors where the air vo'umes V are relatively small. Under these conditions the heat transfer constant K_i is determined more by the peripheral speed of the armature than by the actual air velocity through the motor. Where separate ventilation is used the heat dissipation is practically independent of the armature speed; in this case the above equation is applicable.

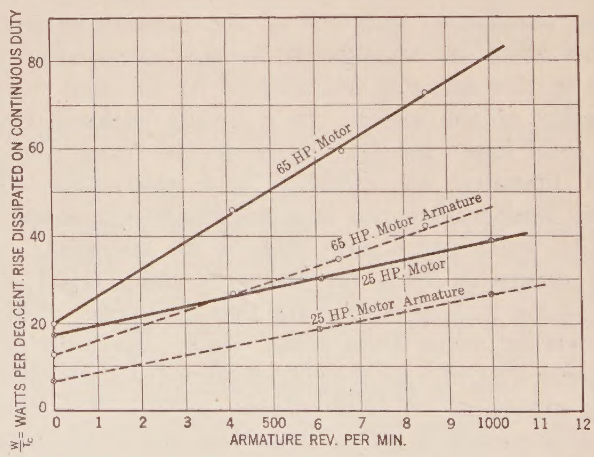


Fig. 2—Heat Loss

In watts per deg. cent. rise dissipated at various speeds at the continuous ratings for the motor and motor armature.

For self-ventilated motors the value of the continuous temperature rise T_c should be based upon test results.

3. The method of solving this problem was first suggested to the writer by Mr. C. E. Wilson.

4. These temperatures are the average surface temperatures as obtained on the iron core.

This value is usually known for two or more speeds, that is the rating at 300 and 450 volts. If the watts loss per degrees centigrade rise (W/T_c) is plotted against the armature rev. per min. the points fall approximately on a straight line as shown in Fig. 2. The value of this constant for zero speed is approximately equal to 0.006 times the external surface of the motor. When the armature only is considered the value of W/T_c becomes approximately equal to 0.003 times the external motor surface for standstill conditions. Hence with one other test point the line is determined.

In equation (**9**)

$$t_1 = 0.06 \frac{(P_a + r\,P_i)}{W} T_c$$

t_1 = The thermal time constant of the motor and is the time in hours necessary to raise the temperature of the motor T_c deg. cent. with the loss W and no ventilation, that is with all of the energy absorbed in the motor.

P_a = Weight in pounds of the motor parts which have losses generated in them.

P_i = Weight in pounds of the motor parts which have no losses generated in them, such as the frame and end housings.

This constant t_1 can also be determined from tests. It is necessary to have a continuous and a short-time temperature test. Substitution in equations (**10**) or (**11**) will give the value of t_1.

Part I of the Appendix is a general solution and can be applied to the motor as a unit or to any part thereof. It may be advisable in some cases to consider the armature alone and in other cases to consider the fields. The temperature rises referred to here are the surface temperatures as measured by thermometers.

Part II gives the method to be used in order to obtain the actual internal copper temperature of the fields or armature windings.

Method of Application

An example will probably clarify the above method for determining the temperature rise of a motor. For instance, calculate the heating curve of a particular 75 h. p. low-speed motor, separately ventilated with 800 cu. ft. of air per minute; the load to be 90 amperes at 600 volts. First find the final surface temperature rise T_c with the loss W, equation (8):

$$T_c = \frac{W}{S_e\,r\,K_e + \dfrac{V\,S_i\,K_i}{V + .9\,S_i\,K_i}}$$

Where:

W = 6610 watts (total motor loss)

S_e = 4740 sq. in. (external frame surface)

r = 0.30 (ratio of frame rise to the internal surface rise)

K_e = 0.013 heat dissipation from frame in watts/sq. in./ deg. cent.

V = 800 cu. ft./min. (air volume)

S_i = 5460 sq. in. (internal ventilating surface)

v = 2070 ft./min. (average air velocity through motor ducts)

K_i = 0.038 (heat dissipation constant, see Fig. 1).

Substituting these constants in the above equation the final rise T_c = 35.5 deg. cent.

The thermal time constant (see Equation **9**) is

$$t_1 = \frac{0.06\,(P_a + r\,P_i)\,T_c}{W}$$

where the weight of active material (P_a) = 1780 lb. and the weight of inactive material (P_i) = 1850 lb. With r, T_c and W as given above $t_1 = 0.774$. Hence with the initial temperature rise (T_s) known the rise at the end of any time (t) can be found from equation (**10**), where

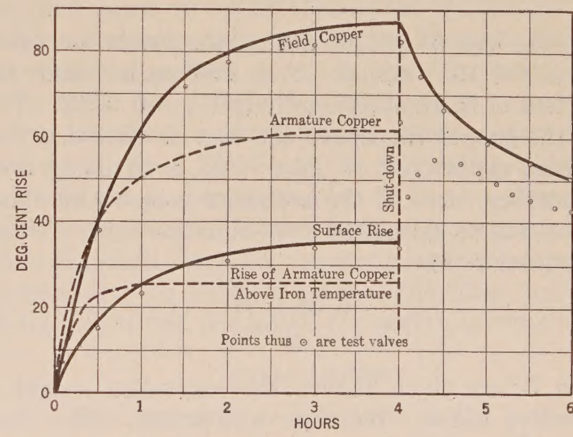


Fig. 3—Heating Curve of 75-H. P. 600-Volt D-C. Railway Motor

Forced ventilation.
Load, 90 amperes, 600 volts.
Curves as calculated.

$$t = 2.3\,t_1 \log_{10} \frac{T_c - T_s}{T_c - T_t}\,.$$

These values are plotted in Fig. 3. The results found in actual tests are also given.

The temperature rise of the armature and field copper can also be found by using the method as given in Part II. The final rise of the commutating-pole copper (see equation 12) is the surface rise, calculated above, plus the insulation drop. Thus

$$T_c = 35.5 + \frac{W\,h}{S_t\,K_t}$$

where the loss W = 1010 watts; insulation thickness (h) = 0.15 in.; the cross-section of the insulation for heat flow S_t = 1180 sq. in. and the thermal conductivity coefficient K_t = 0.0025. Hence the continuous field copper rise T_c = (35.5 + 51.5) = 87 deg. cent.

The surface temperature rise of the coil as given in Fig. 3 is seen to rise abruptly after shut-down when the ventilation is reduced. It is due to the decreased

heat flow from the surface which results in a decrease in the temperature difference between the copper and the surface, in other words, the surface temperature must rise. The maximum point reached after shut-down will be somewhere between the copper temperature and the running surface temperature. The exact value of this will depend upon the thickness of insulation, the relative thermal capacity of the copper and the insulation; and the ratio of the ventilation when running and at shut-down. It is thus seen that this temperature rise of the surface at shut-down is a transient phenomenon and the temperature found by thermometer bears no fixed relation to the actual copper temperature for all conditions.

The final rise of the armature copper T_c above the iron (see equation **12**)

$$= \frac{W\,h}{S_t\,K_t}$$

where the loss $W = 1500$ watts; the insulation thickness $h = 0.10$; surface $S_t = 2280$ sq. in. and the coefficient of thermal conductivity $K_t = 0.0025$. This gives the copper rise above the iron of 26.3 deg. cent or a final copper rise of (26.3 + 35.5) 61.8 deg. cent. The heating curve of the armature copper rise above the iron can be calculated from equation (**10**). Where (see equation **13**)

$$t_1 = \frac{0.05\,P\,T_c}{W}.$$

T_c and W are given above; the equivalent weight of copper $P = 264$ lb. So that $t_1 = 0.231$. The temperature rise of the armature copper above the iron is shown in Fig. 3 plotted in dotted lines. The addition of this to the average surface rise of the motor will give the heating curve of the armature copper.

The air rise

$$T_a = 1.8\,\frac{(W - S_e\,r\,K_e\,T_c)}{V}$$

W being the total motor loss; the factor $(S_e\,r\,K_e\,T_c)$ being the loss dissipated from the frame. Substitution of these constants in the equation gives an air rise of 13.4 deg. cent. Test value was 13 deg. cent.

The following example will show how the temperature rise of a self-ventilated street car motor is calculated for a given cycle run. Given a 25-h. p. 600-volt, 37-ampere, d-c. motor to operate on the following cycle:

(1) A r. m. s. current of 27 amperes for three hours, schedule speed of 10 mi. per hr. with 26-in. diameter wheels and a gear ratio of 13/74.

2) 32 amperes for one hour; schedule speed of 8 mi. per hr.

(3) 27 amperes for two hours, schedule speed of 10 mi. per hr.

(4) 50 amperes for 30 minutes with a schedule speed of 6 mi. per hr.

What will the operating temperatures of the armature iron and copper be under the above cycle?

In this case only the armature is considered. The loss is composed of the copper, iron and stray power, brush and one-half of the friction and windage loss. The following tabulation gives the value of the constants and final equation for obtaining the heating curves of the armature iron or core:

Portion of Cycle	1	2	3	4
Amperes	27	32	27	50
Rev. per min.	735	588	735	441
Total armature loss (W)	937	1056	937	2105
Watts/deg. cent. of iron (see Fig. 2) W/T_c	21.6	18.7	21.6	15.6
Continuous core rise (T_c)	43.3	56.5	43.3	135.4
Weight of armature (P)	200 lb.	..	..	..
Thermal time constant: $t_1 = 0.06\,P\,T_c/W$	0.556	0.642	0.556	0.770

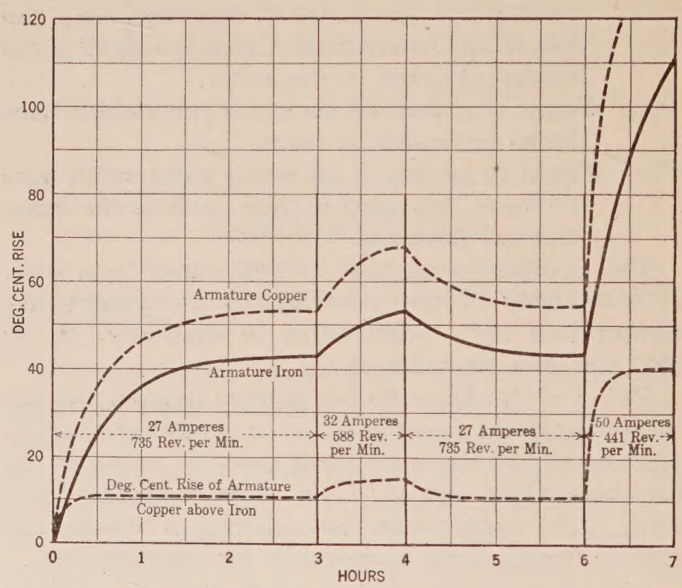


FIG. 4—HEATING CURVE OF ARMATURE IRON AND COPPER
25-h. p. 600-volt d-c. railway motor.

With the above constants the heating curve can be plotted from equation (**10**) where

$$t = 2.3\,t_1 \log_{10} \frac{T_c - T_s}{T_c - T_t}.$$

This curve is shown in Fig. 4 in solid lines.

The following tabulation will give the constants for obtaining the hot-spot correction, that is the maximum internal copper temperature rise above that measured by thermometers on the iron core.

Portion of cycle	1	2	3	4
Amperes	27	32	27	50
Imbedded cop. loss (W)	241	338	241	900

Constant copper rise above iron (see equation **12**):

$$T_c = \frac{W\,h}{S_t\,K_t} = 10.8 \text{ deg.cent. } 15.1 \quad 10.8 \quad 40.3$$

Equivalent copper weight (P) = 45 lb.

Thermal time constant:

$$t_1 = \frac{0.05\, P\, T_c}{W} \text{ (see equation 13) } = 0.101$$

With the above constants the heating curve giving the copper temperature rise above the iron can be found by using equation (**10**) where

$$t = 2.3\, t_1 \log_{10} \frac{T_c - T_s}{T_c - T_t}.$$

This curve is shown in dotted lines (Fig. 4). The addition of this curve to the heating curve obtained for the rise of the armature core will give the heating curve for the armature copper.

Both Figs. 3 and 4 illustrate the fact that the armature copper on the average ventilated motor has comparatively little thermal capacity. It is seen that on loads of thirty minutes or more practically all of the copper loss is being transferred through the insulation. The thermometer measurements will not give this internal temperature, hence it is possible to find a safe temperature rise on a motor by thermometer with a certain load although the motor may be dangerously hot in the inaccessible parts.

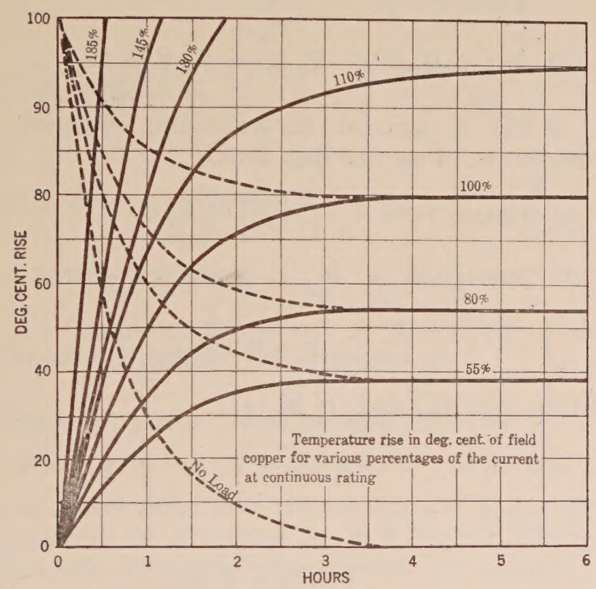


Fig. 5—Heating and Cooling Curves

75-h. p. 600-volt d-c. railway motor. Separately ventilated.

There is no doubt but that from the standpoint of weight and cost the modern ventilated railway motor has an inherent advantage over the totally enclosed motor. It has been shown that since the ventilated motor can get rid of more heat losses than the same motor enclosed it is possible to rate the motor higher. This increases the continuous rating without materially increasing the one-hour or overload rating. The effect of ventilation is to decrease the surface temperature and to increase the gradient between the copper and the surface temperature. When a ventilated motor is applied to an intermittent cycle such as found in railway service, full advantage of the continuous rating cannot be taken since a margin in temperature is necessary in order to carry the heavy peak loads.

With the heavy enclosed motors the ratio of the hour to the continuous rating is high so that the application of such a motor on the basis of the average r. m. s. current is generally safe. The inherent thermal capacity of the motor will usually take care of the peak loads.

On the other hand the tendency of increasing the ventilation is to bring the continuous and the hour rating together. Hence the economical application of the modern high-speed ventilated motors must be made with more care, and the motors' performance from a thermal standpoint on such applications should be known.

The method of predetermining the temperatures of such motors on intermittent service as previously outlined based on actual tests at the continuous rating will give results safer and more accurate than the approximate method given in the Standards of the A. I. E. E. under Rule No. 5502.

For standard motors, heating and cooling curves such as shown in Fig. 5 can be calculated which will facilitate the proper application of these motors. The solid lines are the heating curves at various loads, while the dash lines are the cooling curves either with no-load or with definite loads. The time origin can be shifted to suit the initial temperature conditions.

Conclusions

(1) The temperature limitation is the predominating factor in railway motor application. This limitation is found in the maximum "hot-spot" temperature at the peak loads.

(2) The armature copper has relatively little thermal capacity which may result in high internal temperature gradients on short-time loads.

(3) The ratio of the one-hour to the continuous rating approaches unity as the ventilation of the motor is increased.

(4) The application of the ventilated motor on the basis of the average r. m. s. current to an intermittent duty is incorrect if the maximum internal temperature at the peak load is ignored.

(5) It is the maximum internal temperature which first starts insulation failure. Hence motor ratings should be based upon this temperature and not upon the surface temperature as measured by thermometer.

(6) There is no fixed relation connecting the internal maximum and the surface temperature as found by thermometers. This relation is affected by insulation thickness, degree of ventilation, duration and magnitude of load, together with size and accessibility of the motor windings.

(7) Thermocouple measurements provide the best means for obtaining these maximum temperatures. These temperatures can be approximated from the

maximum hot resistance of the windings. However, the obtaining of these hot resistances requires very quick and accurate work. Either of the above methods requires special apparatus and the services of expert observers in service tests.

It is obvious that the temperatures of a motor in service as obtained by thermometers may be so far from the maximum internal temperatures as to give misleading results.

Thermal characteristics of the motor, such as relation of thermometer to the thermocouple temperatures, must be known for all degrees of load in order to estimate the internal temperatures from the thermometer readings.

(8) The nominal rating as defined by the Standards of the A. I. E. E. and as applied to self-ventilated railway motors is a fictitious rating since it specifies the run to be made under abnormal conditions of ventilation due to the removal of ventilating and commutator covers and due to the fact that the motor speed is usually higher than the average speed found in service. This has resulted in its being no longer a true measure of the motor's thermal capacity. It is merely a measure of the motor's overload capacity under the conditions given.

It would be more logical to make this test under conditions of ventilation as used in service.

The writer, however, believes that the original purpose of the one-hour run, that is a measurement of the motor's thermal capacity, is essential and should be approximated as closely as possible. This can be done either by reducing the time of the run or by reducing the effect of the ventilation.

Appendix

PART I

Temperature Rise of Electric Machines on Continuous and Short-Time Duty

Symbols.

Let W = Total watts loss in motor or part considered.

T_c = Final average surface rise deg. cent. on continuous duty.

T_t = Surface rise at end of time (t).

t = Time in hours the load is applied.

T_s = Average surface rise at start of cycle.

T_a = Temperature rise of ventilating air deg. cent.

V = Cubic feet of air per minute through the machine.

A = Cross-sectional area for air flow in sq. ft.

v = V/A = average air velocity through machine in ft./min.

S_e = External surface of machine in sq. in.

S_i = Internal ventilating surface of machine in sq. in.

K_i = Heat flow from internal ventilating surface in watts/sq. in./deg. cent. See Fig. 1.

K_e = Heat dissipated from external surface in watts/sq. in./deg. cent. Approximately 0.013 when stationary.

r = Approximate ratio of external frame rise to the internal surface rise.

P_a = Weight in pounds of active material.

P_i = Weight in pounds of inactive material.

With a given load applied having a loss of (W) watts for a time (t) the following statement is true:

Total Energy = stored energy + dissipated energy. (1)

But (a) Total energy = $W\,t$

(b) Stored energy = $0.06\,(P_a + r\,P_i)\,(T_t - T_s)$

Note: 0.06 is amount in watt-hours necessary to raise one pound of iron one deg. cent. based on a specific heat of 0.1135.

(c) Dissipated energy

$$= \int_0^t S_e\,K_e\,r\,T_t\,d\,t + \int_0^t S_i\,K_i\,(T_t - T_a/2)\,d\,t$$

(d) But $S_i\,K_i\,(T_t - T_a/2) = T_a\,V/1.8$

$= 0.555\,T_a\,V.$

Note: 0.555 is amount in watt-min. required to raise one cu. ft. of air one deg. cent.

(e) Hence $T_a = \dfrac{2\,S_i\,K_i\,T_t}{1.11\,V + S_i\,K_i}$

(f) Substitute (e) in (c) dissipated energy

$$= \int_0^t T_t \left(S_e\,r\,K_e + \frac{V\,S_i\,K_i}{V + 0.9\,S_i\,K_i}\right) d\,t$$

Substitute (a), (b), and (f) in (1)

$$W\,t = 0.06\,(P_a + r\,P_i)\,(T_t - T_s) + \int_0^t \left(S_e\,r\,K_e + \frac{V\,S_i\,K_i}{V + 0.9\,S_i\,K_i}\right) T_t\,d\,t \qquad (2)$$

Taking the derivative of (2) with respect to t;

$$W = 0.06\,(P_a + r\,P_i)\,\frac{d\,T_t}{d\,t} + \left(S_e\,r\,K_e + \frac{V\,S_i\,K_i}{V + 0.9\,S_i\,K_i}\right) T_t \qquad (3)$$

or

$$\frac{0.06\,(P_a + r\,P_i)\,d\,T_t}{W - T_t\left(S_e\,r\,K_e + \dfrac{V\,S_i\,K_i}{V + 0.9\,S_i\,K_i}\right)} = d\,t \qquad (4)$$

Let $D = S_e\,r\,K_e + \dfrac{V\,S_i\,K_i}{V + 0.9\,S_i\,K_i}$

Hence

$$\frac{0.06\,(P_a + r\,P_i)\,d\,T_t}{W - D\,T_t} = d\,t \qquad (5)$$

The integral of this equation is

$$\int_{T_s}^{T_t} \frac{0.06\,(P_a + r\,P_i)\,d\,T_t}{W - D\,T_t} = \int_0^t d\,t \qquad (6)$$

or $$\frac{-0.06\,(P_a + r\,P_i)}{D} \log_e (W - D\,T_t)\Bigg]_{T_s}^{T_t} = t\Bigg]_0^t$$

or $$\frac{0.06\,(P_a + r\,P_i)}{D} \log_e \frac{W - D\,T_s}{W - D\,T_t} = t \quad \textbf{(6a)}$$

or $$\frac{W - D\,T_s}{W - D\,T_t} = e^{\frac{D\,t}{0.06(P_a + rP_i)}}$$

or $$\frac{W - D\,T_t}{W - D\,T_s} = e^{-\frac{D\,t}{0.06(P_a + rP_i)}} \qquad \textbf{(7)}$$

When t = infinity $T_t = T_c$
Hence $W - D\,T_c = 0$
or $T_c = W/D$

$$= \frac{W}{S_e\,r\,K_e + \dfrac{V\,S_i\,K_i}{V + 0.9\,S_i\,K_i}} \qquad \textbf{(8)}$$

Let $$t_1 = \frac{0.06\,(P_a + r\,P_i)}{D} = \frac{0.06\,(P_a + r\,P_i)\,T_c}{W} \qquad \textbf{(9)}$$

Substitute (8) & (9) in (6a) $$t = t_1 \log_e \frac{(T_c - T_s)}{(T_c - T_t)} \qquad \textbf{(10)}$$

or $$t = 2.3\,t_1 \log_{10} \frac{T_c - T_s}{T_c - T_t}$$

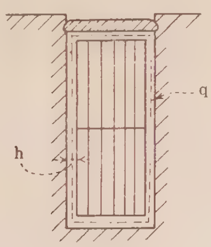
The above can also be expressed as

$$T_t = T_c - (T_c - T_s)\,e^{-t/t_1} \qquad \textbf{(11)}$$

Where (e) is the Naperian base (2.718)

PART II

The above equations (10 or 11) will also apply to the heating of armature or field copper where the factors are defined as given below. A uniform copper temperature is assumed.



W = Total imbedded copper loss.
T_c = Final copper rise above iron.
T_t = Copper rise above iron at time (t).
t = Time in hours load is applied.
T_s = Copper rise above iron at start.

$$T_c = \frac{W\,h}{S_t\,K_t} \qquad \textbf{(12)}$$

Where h = Insulation thickness inches.
S_t = Mean slot periphery (q) × No. of slots × core length.
K_t = Thermal conductivity of insulation in watts/sq. in./deg. cent.
Varies from 0.0025 to 0.0035.

$$t_1 = 0.05\,\frac{P\,T_c}{W} \qquad \textbf{(13)}$$

When P = Equivalent pounds of copper of winding considered.
= 0.32 (volume of copper + 1/4 volume of insulation[1] in cubic inches)

For field winding the same terms are used except as noted below:
W = Total field copper loss.
T_c = Final copper rise above outside surface.
T_t = Copper rise above outside surface at time (t).
T_s = Copper rise above outside surface at start.
S_t = Length of mean coil turn × periphery (q) × No. of coils.

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1. The factor 1/4 is used since the insulation has approximately 1/2 the thermal capacity of copper for the same volume and the insulation rise above its outside surface is 1/2 that of the copper.

A very thorough investigation of oxyacetylene welding and cutting blowpipes was conducted by the Bureau of Standards at the request of the War Department. Apparatus from 14 different manufacturers was submitted to test. This investigation is fully described in Technologic Paper No. 200 of the Bureau of Standards, for sale by the Superintendent of Documents Government Printing Office, Washington, D. C., at 35c. per copy.

An Analytical Investigation of the Causes of Flashing of Synchronous Converters

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The object of this paper is to show on what factors the flashing tendency of synchronous converters depends, and how, on the broadest considerations, an improvement of their momentary overload characteristics can be obtained. From the interpretation of a number of oscillograms, and other experimental data, it is shown that a heavy load surge produces unbalanced armature reactions, resulting in abnormal voltage conditions on the commutation, which are in turn largely responsible for the flash. Synchronous stability, stability of commutating conditions, and means of choking down the flash, are the means enumerated by which the momentary overload capacity may be increased.

DURING the past few years, a noteworthy effort has been made to improve the flashing and the momentary overload characteristics of 60-cycle, 600-volt synchronous converters for railway service. This important work has covered a number of different phases of the problem and has been carried on by the various organizations keenly interested in its success. Some of these phases have been covered by articles and papers published from time to time, describing modifications of design and new methods of protection, while some of the less recent papers explain clearly the very difficult design limitations existing in this type of machine. This literature is referred to in a limited bibliography appended hereto. In the present paper, however, it is intended to deal solely with the processes through which, as a chain of cause and effect, a primary cause leads up to a flash at the commutator. It is particularly important to have a knowledge of this, both to determine effective means of protection and to interpret the varied results of tests.

FLASH ON A 500-KW. 60-CYCLE CONVERTER

There has been a tendency, it is thought, to consider the momentary overload capacity of a converter in too nearly the same terms as that of a direct-current generator. Actually the conditions existing in the two types of machines may be widely different from each other. So long as the converter is operating under steady loads these differences may not be greatly apparent because the alternating and direct currents bear a practically constant relation to each other, and, since they may be considered to flow in opposite directions, the reactive effect is small—less than in any other machine except a fully compensated direct-current generator or motor. The type of overload which is dangerous to the operation of a converter is one which comes on as a heavy surge considerably above the overload setting of the circuit breaker protecting the machine and is consequently relieved in a sudden interruption after a sufficient period has elapsed to permit the circuit breaker to operate. In these circumstances, the internal balance of currents will be severely upset by transfers taking place between the energy of the rotating masses and the energy being converted directly in the armature; resulting in abnormal commutating conditions conducive to flashing. This action then becomes a factor in the overload limitation of the converter. On the other hand, in the case of a direct-current generator the same condition cannot occur; there is but one current in the armature windings and consequently it makes little or no difference whether the input energy is supplied from an external source—a synchronous motor for example—or from the stored energy of its rotating armature.

When a load is applied to a converter, there is a slight momentary drop in speed which results in a permanent phase displacement of the armature behind its position when running light; the displacement being, within certain limits, proportional to the load applied. This action is common to all synchronous machines and is produced by the combined effect of armature reactances and armature reaction. Although the algebraic sum of the alternating-current and the direct-current armature m. m. fs. when summed up over a pole-pitch may be shown to be roughly zero, a study of Fig. 1 will show that in particular points one may be in excess of the other. The direct-current m. m. f. is greater under the interpolar space where the reluctance is high, and the alternating-current m. m. f. under the main pole where the reluctance is much

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lower. It thus happens that the alternating-current part of the resultant m. m. f. is the greater in its influence for reaction than the direct-current part. In addition to this, the resultant direct-current m. m. f. in the commutating zone is neutralized, or even reversed, by the excitation of the commutating-pole winding. The total effect is an appreciable alternating current, or motor reaction, which distorts the main flux backward. The distortion is, naturally, much less than in a synchronous motor, but that it is quite perceptible is shown by Fig. 2, which is an actual field form measurement of a 300-kw. 25-cycle converter. It will be evident that the voltage generated between diametrical rings is no longer a maximum at the instant when the tap-coils pass beneath the direct-current brushes, but at a position on the commutator slightly to the rear, or in the direction against rotation. This point corresponds roughly to the phase displacement.

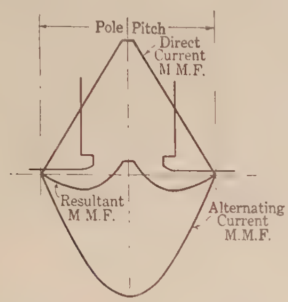

Fig. 1—Armature M. M. F. Diagram for a Synchronous Converter

In order to obtain direct quantitative measurements of this phase displacement, an oscillographic method was developed by which the internal phase relations could be determined. Briefly, the method consisted in recording two voltage waves; one, the voltage applied across two collector rings, and the other, the voltage of an auxiliary machine rigidly connected to the converter armature. The voltage of the auxiliary machine corresponds to a voltage generated by the field winding of the converter alone, without any reactive effects and, therefore, the relative phase positions of the two recording voltage waves may be used to indicate the phase displacement of the converter armature. A very pronounced advantage of such a method is that it may be used for both stable and transient conditions of operation.

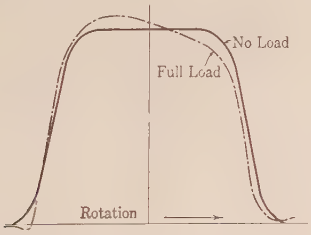

Fig. 2—Converter Field Forms

The phase displacements under various conditions of load were measured on a 500-kw., 60-cycle, 600-volt converter which was used extensively in all the work which these notes cover. It was not used exclusively, however, and the data obtained on it were supplemented to a considerable extent with more from larger machines. The phase displacement results of the 500-kw. converter are shown in Fig. 3. Under stable conditions of load, the results for beyond two and one-half times the rated load, unfortunately, had to be discarded because a sufficient power supply could not be maintained to give steady values. The initial displacement of about one degree is due to the no-load losses of the converter and is, incidentally, purely the action of a synchronous motor. The full-load displacement of six electrical degrees is, as has already been stated, much less than for a corresponding synchronous motor—perhaps only one-fourth of it. To proceed with such a comparison, a synchronous motor may be expected to

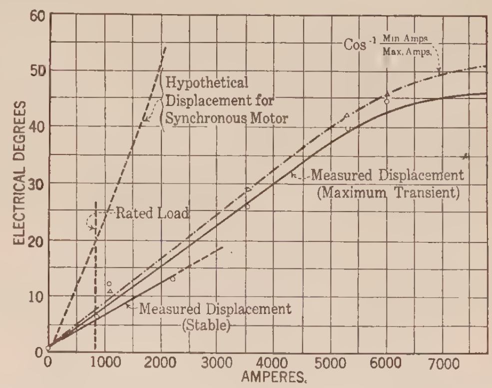

Fig. 3—Relations Between Load Current and Armature Phase Displacement on a 500-Kw., 600-Volt, 60-Cycle Converter

drop out of synchronism at perhaps 2½ times its normal load; whereas a converter will stand very much more, at least ten to twelve times its normal load in the converter referred to, while it may be argued that a mathematically ideal converter would never drop out of step for the reason that as the displacement approaches 90 degrees, the voltage across the direct-current brushes would approach zero while the synchronizing torque approaches a maximum[1]. For practical converters

1. When a synchronous machine connected to a source of constant voltage is placed under load, its rotor is angularly displaced by an amount depending upon the impedance drop in both the intervening circuit and in the machine itself. This displacement is a measure of the stability of the machine; the greater the displacement the less the stability. In a simple diagram, such as Fig. 4, where the resistance drop is neglected, it can be shown that the power flow is proportional to the area between the vectors E_g and E_{g1} and as this varies with the size of the included angle it will be consequently a maximum when the vectors are at right angles, as shown in the second diagram. In other words, this latter condition marks the limit of stable operation and beyond this point the machine will pull out of step. This limitation applies not only to the synchronous machinery but to combinations involving synchronous machinery transformers and transmission lines, etc.

however, high internal losses and flashing will occur before this condition is reached, so that the actual torque will be largely independent of the output and will cause the converter to pull out of synchronism. The tests seem to indicate the displacement may reach a maximum value of 45 electrical degrees before trouble from flashing results.

It is, of course, to be understood that the value of phase displacement of other converters under normal load is not necessarily the six degrees cited above. This quantity depends upon the design of the particular machine involved. The stability of the converter used in these tests is appreciably greater than what is found in machines of larger ratings. It would be expected, and is a fact, that many machines have a considerably larger displacement at their rated loads.

A factor of considerable importance in the determination of the overload capacity of a converter is the characteristics of the circuit supplying the power. The stability of a synchronous motor, for instance, will be sensibly decreased when operated from a circuit of high reactance and the same thing is true of a converter, but to a greater degree because the small reactive effect of the converter itself forms a smaller fraction of the whole; and, conversely, the external reactance will form a *greater* fraction of the whole. For railway substation installations, where it is usual to install transformers with 15 per cent reactance, it will be expected that stability of the converter will be somewhat reduced. To be exact, the above value of reactance is not maintained on heavy overloads, due to the saturation of the leakage paths, but it will be relatively high to the point where the converter drops out of synchronism. Fig. 4 shows this effect quantitatively with very rough assumptions. It is assumed that external reactance amounts to a constant value of 17½ per cent while the converter displacement at normal load is six degrees. The second diagram shows that the maximum load which the converter could carry under these conditions would be about five times its rated value. Since the external displacement is relatively greater than the phase displacement of the converter armature it therefore becomes largely responsible for the machine dropping out of synchronism.[1]

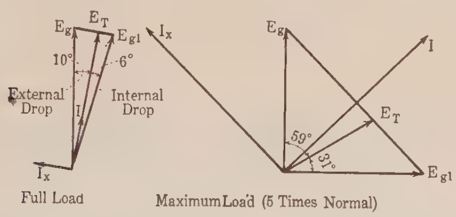

FIG. 4—REACTIVE VOLTAGE DROPS IN A CONVERTER AND SUPPLY LINE

It is to be realized that such a diagram is necessarily very crude and that it can only serve to illustrate a point rather than to give accurate data. Certain factors which have been neglected may however lack the importance which might be given them at first sight. For example, the effect of the series field during such a transient period is not great because any tendency toward sudden changes in flux will be almost completely counteracted by current in the damper winding and shunt field winding for a longer time than it takes the converter to drop out of step. The effect of resistance in the alternating-current circuit will naturally be detrimental although it is usually so small that it is not important except under the heaviest loads.

It follows from the preceding discussion that due to phase displacement in the converter and an additional displacement in any external reactance, the armature takes up a definite phase position for each value of load applied and when a change of load occurs the armature must change its phase position to correspond, moving forward or backward (relatively), depending upon whether the load has been increased or decreased. If the change takes place gradually there will be no resulting disturbance, but if the load changes suddenly the internal balance of currents and reactions will be upset until such time as the armature will have settled into its stable position. When the armature drops back, it delivers a portion of its rotational energy as output at the direct-current brushes which is in addition to the alternating-current input; when it moved forward, extra alternating-current power is required to accelerate it. In consequence of these actions, there is no set instantaneous relation between the alternating-current input and the direct-current output for a transient condition of load, for it will be modified by the rate and direction of energy transfer in the rotating masses.

Hunting is the condition existing when the changes of displacement become oscillatory. In this case, the energy stored in the armature may be taken as fluctuating about a mean value represented by the energy at synchronous speed, and the magnitude of these fluctuations determines the severity of hunting. The relation between the alternating-current input and direct-current output, however, if summed up over an appreciable period is the same as that for the steady load condition.

The sequence of action on the application of load to a converter may be stated in somewhat the following manner: On the closing of the direct-current circuit, the current rises following the ordinary exponential law, being limited at the first instant by only the total inductance of the circuit. The rate of power increase during this period may be high, necessitating a correspondingly high rate of change of armature displacement. If the converter does not fall out of synchronism, the total displacement will be limited to a maximum of less than 90 electrical degrees (see Note 1), but the time in which this movement takes place may be so short that the energy will be given up at a rate comparable to the coincidental output which means

that the converter will absorb a considerable part of the shock of the sudden load change and prevent it from passing into the alternating-current system. This cushioning effect may be achieved in severe cases, however, only at the expense of a flash. Fig. 5 is an oscillogram taken to show the effect of the application and interruption of a heavy load on the 500-kw. converter. The alternating-current wave may be taken as a rough measure of the power input. The alternating current, it may be noted, rises at about one-half the rate of the direct current, and reaches a maximum value only after the direct current has begun to decrease. It eventually exceeds the corresponding value of direct current, which shows that the armature has begun to oscillate freely—that is, to hunt. This effect is much more noticeable after the circuit breaker opens, when the indications of hunting are unmistakable. It is of interest to note that the point of minimum alternating-current input occurs about two cycles after the direct current has been completely interrupted, while at the point at which the direct current reaches zero the power required to accelerate the rotor is scaled at about double the rated input of the converter.

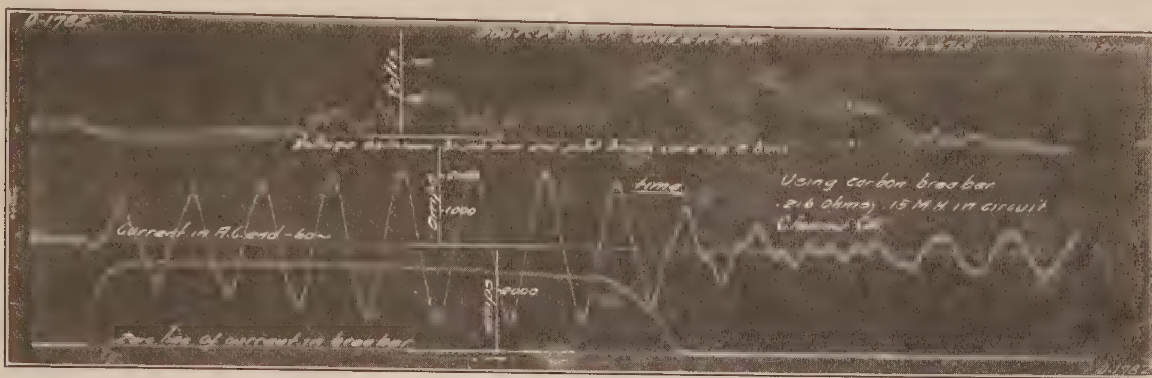

Fig. 5—Application and Interruption of a Load on a 500-Kw. Converter

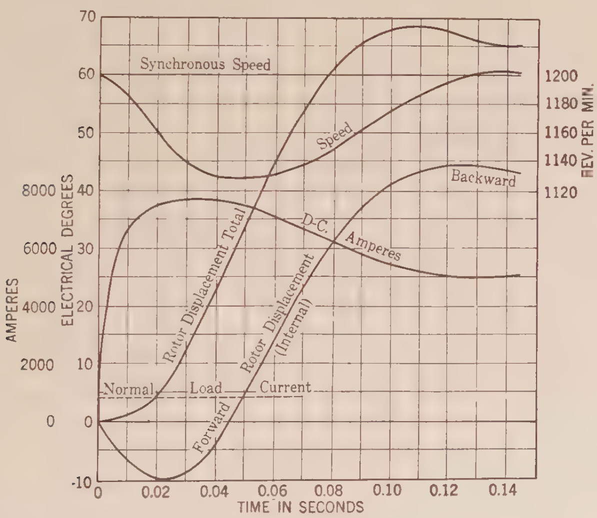

Fig. 6—Transient Relations of Speed and Displacement in a 500-Kw., 60-Cycle Converter

This brief analysis gives a general idea of the power fluctuations under such circumstances; but, while very interesting, it fails to give a quantitative measurement of the displacement angles involved. To obtain these data, a series of tests was made while loads of various magnitudes were thrown on the converter, the results of which are plotted in Fig. 3 where they can be compared with the corresponding displacements under steady load. The maximum transient displacement is the greater as is logical. The curve shows a tendency for the internal displacement not to increase beyond 45 electrical degrees which may be the actual case.

The complete results of one test are combined in Fig. 6. The short-circuit current rose to a maximum value of about 9½ times the normal value in 0.03 second, and then decreased to about six times full-load current. This load is obviously too great to be maintained by the converter, but, if this had been possible, the final and stable value would have been between these two, though considerably nearer the lower one. The maximum angle of internal phase displacement recorded was 43 degrees which occurred roughly at the instant of minimum current. This is again indicative of oscillatory action. A distinction is made between total displacement and internal displacement; the former term applies to the amount by which the converter drops back into phase position behind the source of power, and thus is the result of the entire reactive drop between that source of power and the armature as well as that in the converter itself. It is this quantity which determines the amount of rotational energy given up by the rotating parts. The internal displacement includes only that which is produced within the converter due to the effective armature reaction and reactance. One point which is worthy of note, and which came as a surprise, is the fact that the initial *internal* displacement is forward instead of backward as might be expected. This simply means that the external displacement due to line reactance, etc., increases faster than the armature can initially drop back. The total displacement is, of course, always backward. This short-circuit test approached

the limit of severity which could be thrown on the converter without having it drop out of synchronism. An indication of this is the fact that the total displacement reached a value of 70 electrical degrees. As a matter of fact, it was only the very low value of external reactance which explains why the converter remained in synchronism at all at such a load.

It might be noted in passing that the decrease of load current after the maximum value is reached is closely associated with the phenomenon of phase displacement; and, incidentally, the relation between the two was at first made use of to obtain quantitative measurements of internal displacement. With a constant sinusoidal voltage applied to the rings, the voltage across the direct-current brushes will drop with the cosine of the angle of displacement. If the load current were assumed to drop off also according to this same law, then the ratio of the current at the first dip to the maximum value will represent the internal displacement. That this assumption is more or less justified may be drawn from the comparison of curves of Fig. 3. In the case of another machine the agreement might not be so close, although the method ought to serve at least as a means of comparison between different tests on the same machine.

The magnitude of the energy fluctuations in the converter during short circuits can be estimated from the inertia of its rotating masses and the data of Fig. 6. In this particular case, the energy given up by the armature in the first 0.04 second was about 30,000 ft-lb., and at a maximum rate of 1250 kw. This is about two and one-half times the rated capacity of the machine and amounts to about 50 per cent of the actual output during this period. These figures, therefore, agree with the conclusions drawn from Fig. 5, and serve to demonstrate the fact that the fluctuations of energy which disturb the balance of the reactors are severe.

These figures may also be used as a means of showing the resultant effect on commutation. Assume that the instantaneous ratio of output to input is 2:1; the m. m. f. acting in the commutating zone instead of being the 10 per cent of Fig. 1 becomes 55 per cent of the full direct-current armature ampere turns and if, as was formerly quite usual, the commutating-pole ampere turns amount to only about 40 per cent of this same value, there will be a negative m. m. f. of 15 per cent to produce a flux in the reverse direction. Under such conditions it would be much better for the converter if the commutating poles were removed.

The obvious way to reduce the amount of trouble from this source is to increase the magnetic strength of the commutating pole in relation to the armature until it becomes comparable to that of a direct-current generator. If this be done, the extra ampere turns under normal operating conditions will be used up in a greatly increased reluctance of the commutating pole, while under load surges they will prevent the commutating-pole flux from becoming greatly decreased (relatively) or reversed. This arrangement has become known as a high-reluctance commutating pole, the reluctance being obtained by placing non-magnetic material (which includes air) in the magnetic circuit of the pole. If the strength be increased to 100 per cent, for instance, the conditions referred to above become as follows: In the case of stable operation, 10 per cent of the total m. m. f. is utilized in neutralizing the resultant m. m. f. of the armature and the remaining 90 per cent in overcoming the reluctance of the magnetic circuit. In the case of the assumed surge, 55 per cent neutralizing m. m. f. is required, leaving 45 per cent to produce the commutating flux which means that the latter will be one-half of what it would be under the corresponding stable condition.

These rough calculations have been verified experimentally, using the same converter as in the former tests furnished with high-reluctance commutating poles of approximately 100 per cent strength. The data obtained are plotted in Fig. 7. The flux changes were recorded by an oscillograph connected to search

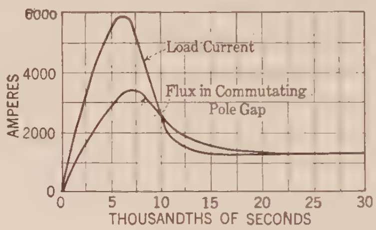

Fig. 7—Relations Between Load Current and Commutating-Pole Flux under Transient Conditions

coils in the commutating zone. The flux harmonics are large under short-circuit conditions, so that to reduce the possibility of error from this cause two oscillograms were used to produce the one composite curve. As there was no pronounced difference between the separate curves, it is probable that the result is reasonably accurate. The ordinates of flux and current have been made to coincide for purposes of comparison.

The phenomena following the interruption of a heavy load are equally important to those of an increasing surge. It has already been mentioned in connection with Fig. 5 that when the direct current was completely interrupted the alternating current still amounted to double its rated value. At th s t me there were no other m. m. fs. acting in the commutating zone, and the only obstruction to the passage of flux was the reluctance of the magnetic circuit. The condition corresponds to a strongly over-compensating commutating pole[2] and tends to occur on all occasions when the load is suddenly reduced.

In Fig. 7, the period intervening between 0.01 to 0.02 second is one of over-compensation due to the sudden operation of the circuit breaker. The excess

2. The alternating-current m. m. f. of the armature acts in the same direction as the m. m. f. of the commutating-pole series winding.

here is not great for the armature was never displaced to any great extent, and therefore required little accelerating current.

Referring again to the results of Fig. 5, it is possible to make a rough estimate of the flux produced by the unbalanced armature current at the interruption of the direct-current circuit on the same basis as those already made. Assuming then the alternating current to be double the rated value and a commutating pole of 40 per cent of armature strength, the commutating flux will tend to increase to a maximum value of between five and six times that at normal load and will, naturally, generate high voltages under the brush. If a high-reluctance commutating pole of 100 per cent strength is supplied to the converter, the corresponding flux will tend to be only about double the normal value at full load. The pronounced advantage of the high-reluctance commutating pole for the condition of quickly decreasing loads is, therefore, also evident. It might be remarked parenthetically that there is a practical limit to which the increase of reluctance of the commutating pole may be carried. This comprises only one of the possible paths for the flux (others being slot leakage etc.), so that when the reluctance of the commutating-pole circuit become relatively high compared to that of the other paths, the practical limit is reached. The constructional difficulties, of course, increase with the reluctance.

The amount of energy unbalance under transient conditions of load is a measure of the combined effect of several factors which may be conveniently grouped under two headings: First, the extent of change and the rate of change of the load; and second, the relation between the moment of inertia of the rotating element and the electrodynamic stability between the converter and its source of power. The 500-kw. converter used particularly for these tests was one of low moment of inertia and high stability at its rated load due to the design limitations for this type of machine. As a consequence, the overload capacity under both stable and transient loads was exceptionally high. Converters of greater ratings are not so fortunate in this respect; their inertia is relatively greater and their stability less. The data submitted here, therefore, cannot be taken to apply indiscriminately to all classes of machines but must be modified to suit the design proportions for individual cases. The test represented by Fig. 6 for instance, showed that the 500-kw. converter used will carry 9½ times its rated load without dropping out of step or flashing. This cannot be considered a representative figure, by any means, for converters in general, and in addition to this the same converter when operated from high-reactance transformers would not have this overload capacity.

Up to the present point, the converter has been dealt with as a piece of synchronous apparatus entirely, particular attention having been paid to the character of reactions resulting from transient load conditions. The phenomenon of flashing itself is a characteristic of commutating machinery; therefore to show the relation between these reactions and the flashing which may result the converter must be dealt with as a commutating machine. From a careful examination of the available data in the form of oscillograms, high-speed photographs, etc., the immediate causes leading up to a flash-over were ascertained to be in the majority of cases as follows: Sparking under the brushes occurs with heavy overloads in all commutating machinery and is due partly to the heavy currents flowing across the brush contact surfaces, but more to the imperfect compensation of inductive voltages generated in the short-circuit coils effected by the excitation of the commutating pole. Sparking will naturally precede a flash, even though perhaps only for a few thousandths of a second. It produces ionization of the atmosphere at the surface of the commutator which decreases the ability of the converter to resist the first formation of an arc. In nearly every case capable of investigation, the flash developed through the sparking at the brushes being drawn out as the commutator bars receded from the brush until the arc extended through an entire pole-pitch. When this occurs and the arc is between brush arms of opposite polarity, or between brush arm and ground, the flash may be considered completely developed. Experience with electric welding has shown that 20 volts are sufficient to maintain an arc, and although conditions are somewhat different on the commutator, the presence of ionized gases due to sparking is favorable to the initiation of an arc, and the above voltage or probably a higher value indicates the magnitude necessary for flashing. If the above conclusions be generally correct, it means that the voltage conditions and distribution over the commutator, in particular directly ahead of the brushes, *i. e.*, in the direction of rotation, are critical for the propagation of an arc and the development of a flash.

It has been generally appreciated that a converter is far more liable to flash on the opening of the circuit breaker than at the point of maximum current. An investigation of the voltage distribution over the commutator under the two conditions—that of increasing loads, and that of decreasing loads—gives the explanation for this. Take the case of a non-commutating-pole, direct-current machine; here, when loaded, the neutral shifts forward for a generator, and backward for a motor, as is evidenced by the necessity for the shifting of the brushes. In the case of the converter when hunting takes place, very much the same thing is true; the fluctuations of energy in the rotating element represent unbalanced motor or generator reactions and the neutral swings backward or forward of the brush as the machine oscillates in phase position. This effect is plainly observable from the sparking under the brushes which will rise and subside with each oscillation. When the generator reaction is in excess and the neutral is ahead of the brushes, the

voltage between a brush and a receding bar is of opposite polarity from normal until the bar is somewhat past the neutral. It is evident that there is no voltage between the brush holder and the commutator capable of propagating an arc forward until after the bar has reached a point where the voltage has risen to an appreciable value in a positive direction, and as this point may be an inch or more from the brush on the commutator surface, the conditions are very unfavorable for production of a flash.

In the case of an excess motor reaction, the neutral has moved backward and the bar, on passing the brush, is moving into a field of steadily increasing intensity, and the voltage gradient over the commutator directly in front of the brush may be much higher than it normally is. A critical voltage, which is readily able to carry the arc forward to the next brush arm, may exist on the commutator almost at the brush itself, and thus the danger of flashing is imminent.

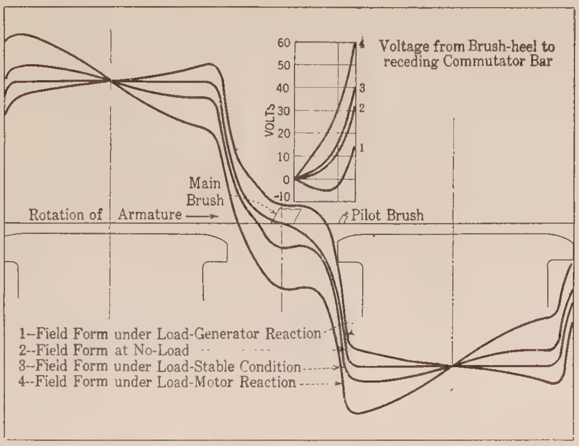

Fig. 8—Field Forms and Voltage Conditions for Various Types of Load

To present this condition in a more definite manner, Fig. 8, which gives several calculated field forms of a converter, has been included. The field forms are drawn up for four different conditions of load, which are, referring to the numbers on the curves: (2) at no-load, (3) under a stable load condition, (4) under load with excess motor reaction, (1) under load with excess generator reaction. The same output has been assumed in each of these last three cases to allow direct comparison; the difference of field form being produced, therefore, by the transfers of rotational energy causing unbalanced reactions.

The changes of flux in the commutating zone between the conditions (1), (3) and (4) are quite marked, although the flux for proper compensation should be the same in each case. The corresponding shifts of the neutral are equally pronounced. If, for instance, the converter were hunting with sufficient severity to produce the unbalanced reactions of this figure, the neutral would swing between the two extremes (1) and (4) with each oscillation.

The inset voltage curves refer to the voltage difference between the heel of a brush and a commutator bar, as it moves forward. They represent in a way the relative tendencies toward flashing for the conditions of operation assumed. At no-load this voltage at the point marked "pilot-brush" is given as 12 volts, which corresponds to that actually measured on the converter. Under the stable load, this voltage is increased only slightly. The same load, while increasing, produces a voltage of − 3 volts at this point, and while decreasing + 30 volts. The significance of these voltages may be inferred from the consideration that if 25 volts are required to maintain an arc on the commutator, in the former case no such voltage will exist on the commutator until the bar has receded a considerable distance from the brush, and it is unlikely that an arc will be propagated forward. In the latter case, a critical voltage may exist almost at the heel of the brush, and the conditions are entirely in favor of the propagation of a flash. It may be said, therefore, that during a period of increasing load a converter is in a sense self-protecting against a serious flash; but that when a load is suddenly decreased, as when a circuit breaker opens, a flash is much more likely to occur, a conclusion thoroughly borne out by experience.

In order to obtain some direct information on this particular action, a number of short-circuit tests was made on the converter having a small pilot-brush located on the commutator at the point indicated in Fig. 8. By this means, the voltages in the commutating zone, critical from the standpoint of flashing, were measured under various transient conditions and the results form a striking confirmation of the theory outlined above. In Fig. 5, the upper line is a record of this voltage. Before the application of the short circuit this "pilot-brush voltage" was about 12 volts, but during the sudden increase of load it dropped slightly below zero, meaning that the neutral had swung forward. Under the steady load condition, it rose to nearly 50 volts above zero, indicating that the neutral was permanently displaced backward. At the opening of the circuit breaker, the voltage exceeded 100, indicating that the decreasing load forced the neutral backward although the armature itself was being accelerated forward. Unfortunately, the oscillogram ended just as a period of free oscillation was beginning, although the commencement of the characteristic indications are evident.

Fig. 9 is a somewhat similar oscillogram but taken during a much heavier short circuit. The current reached a value of 9750 amperes or about 11½ times normal value and the effects are, therefore, sufficiently pronounced to repay a rather detailed study, through which a relatively complete history of the internal actions during the test may be traced. The negative pilot-brush voltage indicates the release of stored rotational energy as in Fig. 5, but at a higher rate for the voltage here drops to 80-90 volts. This is sufficient

to convert the sparking at the brushes into a flash which is indicated by the dip in the current wave. However, as the position of the neutral was far forward, the flash was not propagated to the next brush arm and it existed more in the form of a momentary "spit" of considerable severity. As the neutral receded backward with the increase of phase displacement, the voltage initiating the flash decreased to a point in excess of anything which might reasonably be expected of the converter. To permit this performance, the apparatus used included several special features. The converter itself was furnished with high reluctance commutating poles, such as have already been referred to. Flash-guards were placed on either side of the direct-current brush arms to insulate the brush holders from conducting gases, and a special arrangement of

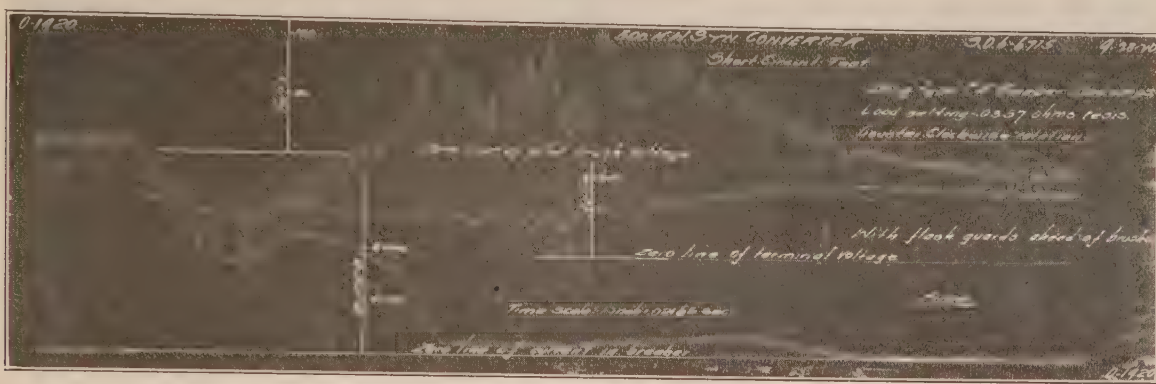

FIG. 9—HEAVY SHORT CIRCUIT ON A 500-KW. CONVERTER

where this flash stopped entirely (where the current dip ends). The transition to the stable condition was never completed in this phase of the test, for the circuit breaker opened while the armature was still moving backward. At the interruption of the direct-current circuit, the pilot-brush voltage rose immediately to a maximum value of perhaps 120 volts, which represents a greatly aggravated case of (4) of Fig. 8. At this point the converter flashed the second time but with the reversed voltage conditions on the commutator and as there was nothing to stay the progress of the flash, it progressed completely to the next brush arm where it would have developed seriously had it not been for flash guards supplied to the forward side of the brush holders which isolated the arc on the moving surface of the commutator. This effect greatly limited the severity of the flash and choked down the amount of power expended, so that the armature was allowed to move forward in phase displacement. Thereupon, the unbalanced reaction dropped in value and the neutral approached its normal position again. This proceeding cut off the means whereby the flash was continually being propagated forward and the arc naturally died out. The beginning of the regular descent of the pilot-brush voltage, in Fig. 9, indicates the cessation of flashing. This second flash was of rather short duration as well as the first. If the flash had reached some unguarded point of opposite potential, as would have been the case without the protection of flash guards, it would have been necessary to shut down the machine to kill the arc and protect it from serious injury.

This test fairly exemplifies the principles advanced in the previous part of this paper. It represents as well, a service of extreme severity and considerably brush-holder cross-connections was used to control the flash to a certain extent. The transformers used were of lower reactance to reduce the external impedance to a minimum. The circuit breaker was set for a slightly higher speed than would ordinarily have been considered necessary so that it might operate before the armature had reached its maximum displacement. This was essential to prevent the converter from dropping out of synchronism on extreme momentary overloads. The circuit breaker actually began to open in 0.06 second while the maximum displacement occurred in the neighborhood of 0.08 second. It may be observed that the circuit breaker did not completely open the direct-current circuit in this test; this is because a resistor had been connected across its contacts for previous tests, but there is no particular significance of it in the present connection. This general arrangement, however, tends to reduce the probability of flashing.

This short-circuit test did no injury to the converter beyond a certain amount of erosion of the brush surfaces caused by the heavy load current and circulating current in the brushes. The machine was not shut down and it was found practicable to place it under load again immediately, although not to its full rated capacity until the brush surface conditions had become somewhat improved.

Two more tests taken under a different condition will be referred to. For these tests, the converter was protected by a high-speed circuit breaker by which is meant one which will completely operate within 0.01 of a second. Fig. 7, although not quite typical on account of the time of operation being slow, shows the characteristic current curve very plainly. By making a comparison between this figure and Fig. 6

on a time basis, it may be noted that the initial rates of current rise are not widely different so that the displacements for the two tests may be assumed to correspond with the same accuracy. With the current limited to a time of 0.006 or 0.007 of a second the resulting displacement must be very small; and in fact the internal displacement of the converter will be forward, as has been independently verified. In order that an idea may be gained of the transient phenomena involved Fig. 10 is referred to. The test shown here duplicates that of Fig. 7 except that different quantities were recorded. The fluctuations of both alternating current and of the pilot-brush voltage are so small that it is evident that the great speed of the circuit breaker forestalls any pronounced internal disturbance. Both of these tests represent dead short circuits thrown on the converter, demonstrating that complete protection may be obtained in this manner. Fig. 11 is reproduced from a photograph taken during one of these tests.

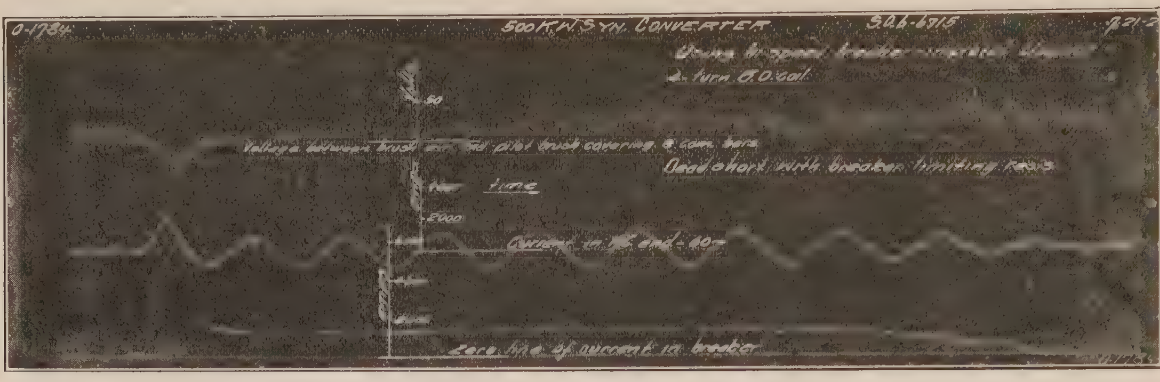

Fig. 10—Action of a High-Speed Circuit Breaker

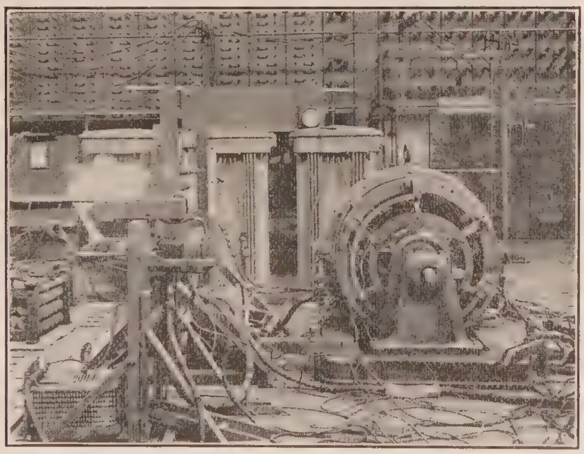

Fig. 11—Dead Short Circuit on a 500-Kw. Converter Portected by a High-Speed Circuit Breaker. (See Fig. 10.)

Fig. 12 is from a multi-exposure photograph taken with a high-speed camera[3] to study the development of a flash on the commutator. To compress the phenomenon within the limited time, the high-speed circuit breaker was used with certain modifications to permit the formation of a flash. The exposures are numbered consecutively 1, 2, 3, etc. and are taken 0.001 of a second apart. From comparing these exposures with the oscillogram taken on the same occasion, exposure No. 6 is found to occur at the instant of maximum current, which was 8200 amperes. Up to this point, it may be noted that the flash did not develop beyond the category of a severe spit; at the sudden opening of the circuit breaker, however, the following exposures 7, 8 and 9 show sudden expansion forward of the flash which takes place at even a faster rate than the motion of the commutator itself. These photographs, which record the actual state and confines of a flash at successive intervals over a period of rise and decay of load current, form an important support to the conclusions regarding the propagation of an arc under these two conditions, as set forth in some of the foregoing paragraphs.

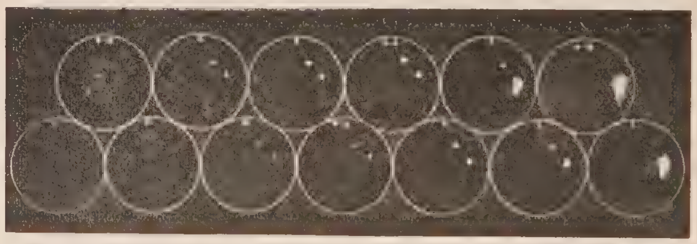

Fig. 12—Development of a Flash on the Commutator

The principles set forth in this paper showing the very intimate connection between the synchronous action of a converter and the flashing at the commutator are the outcome of a series of tests extending over several years and a careful analysis of all available data whether derived from these tests or from other sources. It is believed that the conclusions are substantially correct and that they can be used to cover other similar phases of the problem not mentioned here. By applying these principles to the problem of increasing the

3. J. Legg. The Polar Multi-Exposure High-Speed Camera, *Electric Journal*, December, 1919.

momentary overload capacity of converters, the following main lines of progress are suggested:

(1) The improvement of synchronous characteristics of the converter installation to obtain high stability and the reduction of the moment of inertia of the rotating masses of the converter.

(2) The reduction of the effectiveness of the unbalanced reactions in producing high voltages in the commutating zone. (High-reluctance commutating poles are an instance of this).

(3) The prevention of the complete propagation or culmination of the arc by the insulation of conducting parts around the commutator by means of flash-guards and other devices.

(4) The limitation, by external means, of the maximum severity of the surges thrown on the machine. (In which might be included the high-speed circuit breaker).

These principles have been utilized in devising suitable means of improving the characteristics of commercial types of 60-cycle railway synchronous converters with the result that they have proved themselves much superior to their predecessors.

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RADIO DIRECTION FINDER

The U. S. Department of Commerce has developed a system of radio direction finding to be applied to navigation, in which the direction finder is located on board ship and receives signals transmitted from a radio station on shore. This development has been carried on by the Bureau of Standards and the Bureau of Lighthouses in cooperation. Three radio transmitting stations have been established on lightvessels and lighthouses at the approaches to New York Harbor, and a fourth is in process of installation on San Francisco Lightvessel. The three stations in commission have been giving very satisfactory service.

The location of the direction finder on board ship instead of on shore has a number of advantages of which some of the more important are: The navigator of the ship can himself take the radio bearings, position can be determined promptly, and bearings taken as often as desired.

The radio direction finder is particularly useful in times of fog or poor visibility, and in case of shipwreck may be the means of saving many lives.

The Bureau of Standards has made studies of radio direction finding apparatus, extending over the past nine years. One important consideration which has received careful attention is the distortion effects which may result from the presence of adjacent objects, such as a ship, and methods of eliminating errors which such distortions may cause in observed radio bearings. The radio direction finder on board ship may be calibrated just as is the ship's magnetic compass.

A common type of direction finder for installation on shipboard consists of a coil of ten turns of insulated copper wire wound on a wooden frame four feet square, mounted so that it may be rotated about a vertical axis. The radio direction finder as used by the Department of Commerce involves a number of unique features. It is designed to be installed over the ship's binnacle carrying the magnetic compass card, on which the radio bearings are read directly. An additional scale is attached to the top of the binnacle and marked with the corrections obtained by calibrating the radio direction finder. By these means the radio bearings are obtained in a simple and direct manner, the only operations necessary being the adjustment in the radio receiving set and the rotating of the direction finder coil.

The Bureau of Standards has recently issued a publication describing this system of direction finding. Illustrations are given of a radio direction finder of the type mentioned above installed on the pilot house of a lighthouse tender. Actual courses are shown which were run by means of radio bearings taken by the ship's navigator, on the three beacons at the approaches to New York Harbor. The paper deals briefly with the principles of the operation of the direction finder, but it is primarily concerned with its practical application and the development which has made possible a device sufficiently simple and accurate for use as an aid to navigation. Every person connected with radio or with navigation will find this paper of considerable interest. It is known as Bureau of Standards Scientific Paper No. 428, "The Radio Direction Finder and Its Application to Navigation."

Key West–Havana Submarine Telephone Cable System

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The system discussed in this paper includes three single-core continuously loaded submarine cables, each of which provides, in addition to a telephone channel, direct-current and carrier-current duplex telegraph channels. A description is given of the design and construction of the cables, of the method of superposing the various channels on each cable and of the terminal apparatus used for their operation.

ON April 11, 1921, commercial telephone service was inaugurated between the United States and Cuba over three submarine cables laid across the Florida Straits between Key West, Florida and Havana, Cuba. These submarine cables are the longest and most deeply submerged which are in use for telephonic communication. They are from 100.2 to 104.9 nautical miles (186 to 195 km.) in length and are laid in water which for a part of the route is about 1000 fathoms (1830 m.) in depth.

The location of these cables and some of the important toll lines in the United States and Cuba are shown in Fig. 1. The cables were installed by the Cuban-American Telephone and Telegraph Company, an organization formed in 1919 by the American Telephone and Telegraph Company and the Cuban Telephone Company, for the purpose of providing telephone facilities between the United States and Cuba which would be suitable for connecting the telephone toll lines in the two countries.

The design of the submarine cables and the associated terminal equipment differs from previous systems because of the service which is furnished, the depth of water in which the cables are laid, and the length of the cables. The general features of this system will be indicated by the following summary of the requirements and the means which have been employed to meet them.

FIG. 1—MAP SHOWING THE SUBMARINE CABLES AND SOME OF THE IMPORTANT TOLL ROUTES IN THE UNITED STATES AND CUBA

To give the service desired over these cables, it was necessary that the telephone channels be suitable for use in circuits connecting points in the United States, such as New York and Chicago, 1557 and 2453 miles (2510 and 3940 km.) distant from Key West, with Havana and other points in Cuba, which is about

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700 miles (1126 km.) in length. It was required also that the cables furnish, simultaneously with the telephone, a number of telegraph channels. These are provided partly by direct-current channels and partly by carrier-current channels[1] using frequencies above the telephone range.

Because of the depth of water and other conditions, the cables are of the single-core type, generally used for deep sea submarine telegraphy in which the return path of the circuit is through the sea. An important modification of this type has been made for these cables in order to make the circuits more suitable for telephone and carrier use. This consists in surrounding the insulation of the central conductor with a wrapping of copper tapes forming an uninsulated return conductor.

In order to obtain the necessary efficiency for the telephone channels over cables of this length, the cables are "loaded," that is, the inductance of the circuit is increased by the use of iron, and vacuum-tube repeaters[2] are used at the terminals for all connections over the cables.

To provide the desired services, required, in addition to laying the submarine cables, the extension in the United States of suitable toll lines to Key West and the installation of vacuum-tube repeaters in the Cuban toll lines.

General Design of System

The construction of an open-wire land line along the causeway of the Florida East Coast Railroad which connects the string of small islands off the southern end of Florida, made it possible to land the cables at Key West and thus materially reduce their length. The landing points of the cables are on the western side of the entrance to the harbor of Havana and the southern side of the Island of Key West. This point in Havana is about a mile (1.6 km.) from the telephone toll office and that in Key West an equal distance from the existing telephone office. The distances from the cable landing points to the telephone terminal offices were kept as short as practicable in order to reduce the possibilities of interference from power circuits.

The water in the Florida Straits, starting from Key West, increases gradually in depth. Five miles (9.3 km.) from shore it is about 40 feet (12.2 m.) deep, at 15 miles (27.8 km.) about 700 feet (214 m.), and at 35 miles (65 km.) about 3000 feet. (915 m.) From that point on to within about three miles (5.6 km.) of Havana it is from 3000 feet (915 m.) to 6000 feet (1830 m.) in depth, being about a mile (1.86 km.) deep within five miles (9.3 km.) of Havana. These depths of water eliminated from consideration the use of a paper-insulated cable such as is commonly employed for telephone purposes on land or in shallow water. The most suitable construction for great depths is the submarine telegraph type of cable with an insulation of gutta-percha or similar material.

Previous gutta-percha or rubber-insulated submarine telephone cables have, in general, contained four cores arranged to provide three and sometimes four telephone circuits. Two of these circuits, the "physicals," have been obtained directly from the two pairs of wires, one superposed circuit, the "phantom, has been obtained from the two wires of each pair in parallel and in some cases a second superposed circuit has been formed by the four wires in parallel with a sea return. There was considerable question, however, in this case whether a cable of this type could be sufficiently well balanced to keep the cross-talk between the two superposed circuits and the physical circuits low enough to permit of their simultaneous operation with the required amplifications.

In comparing the four-core cable with a system consisting of three single-core cables, the following factors were important: First, the cross-talk factor; second, the lack of any experience with laying and repairing four-core cables in water of these depths; third, the relative cost of the two systems; and fourth, the superiority of the single-core cables from the important standpoint of insuring continuity of service, at least for an initial installation of cables. A consideration of all these factors led to the adoption of single-core cables for this case.

The inductance of a circuit may be increased by the periodic insertion of loading coils, or by "continuous" loading, which is the wrapping of iron wire or tape around the conductor. Because of the depths of water involved, the use of loading coils was impracticable. The placing of such coils in a cable causes, at the points of insertion, changes in the size and construction of the cable which are sources of weakness, both in connection with the stresses imposed on the cable in laying and repairing and also because of the necessity of making the cable resist the penetration of water, which at the deepest point reaches a pressure of over a ton per square inch (140 kg. per sq. cm.). The use of continuous loading for these conditions is advantageous not only mechanically in that it gives a uniform structure but also from the standpoint of keeping the terminal impedance of the cable uniform over the range of frequencies to be used. In repairing a coil-loaded cable in deep water it is practically impossible to maintain the regular spacing of the coils which is necessary for this uniformity of impedance. This uniformity is important in obtaining the close balance between the impedance of the cable and that of a network of impedance elements which is required for the two-way operation of amplifiers on the circuit.

These cables were planned to provide New York-Havana connections for which a transmission equivalent of under fifteen miles of standard cable (cable having resistance of 88 ohms and capacity of 0.054 microfarad

1. Colpitts and Blackwell, "Carrier Current Telephony and Telegraphy" Journal A. I. E. E., April, May and June, 1921.

2. Gherardi and Jewett, "Telephone Repeaters" A. I. E. E. Trans., pp. 1287 to 1345, 1919.

per loop mile) was desired. Since the operating equivalent of the New York-Key West portion of the circuit is about ten miles, the sum of the amplifications applied at the terminals of the cable must be within five miles of its equivalent. It was estimated that practicable cables could be obtained which would have transmission equivalents of about 25 miles of standard cable. This required that the amplifications at the terminals should average about ten miles. As the interference produced on such a cable by power systems, by other communication systems, and by natural disturbances and the cross-talk between the cables themselves are amplified also, the requirements for these factors were correspondingly more exacting.

To reduce the interference at the terminals of the cables from local power circuits, two-wire metallic circuits are used from the telephone offices to the landing points and the submarine cables are connected to the land lines through transformers so that these lines are balanced to ground. The operation of direct-current telegraph over the cables requires, however, that connections be arranged for carrying these telegraph channels around the transformers.

Operation of Single-Core Continuously Loaded Cables

The preliminary studies of the results to be expected with a loaded "grounded" cable circuit arranged for simultaneous telephone and telegraph operation indicated that satisfactory operation was dependent upon a number of factors regarding which little information was available. These included the effect of the sea return on the attenuation for alternating currents, the interference from natural electrical disturbances and from power systems at the terminals, the induction between cables and the interaction between currents of different frequencies resulting from their superposed fields in the iron used for loading.[3]

The effect of the sea return for the single-core cables used for submarine telegraphy has not been serious because it is practically negligible for the low frequencies involved. For direct currents, the cross-section of the return path is very large and its resistance low, even though the specific resistance of sea water is relatively high, of the order of ten million times as great as that of copper. For alternating currents, however, the return currents crowd in near the cable and the resistance of the return path is higher. This crowding effect of the return currents increases with frequency and consequently the resistance of the return path becomes greater. For frequencies in and above the telephone range the return currents are forced into the steel armor wires around the cable and into the layer of water just outside of the insulation. The small effective cross-section of the water involved and the losses in the armor wires cause the resistance of the return path to become a large part of the total resistance of the circuit and thus to have a large influence on the attenuation. The results of a few measurements of the sea return resistance for telephone frequencies, which had been made by British and French engineers, were published[4] in 1913 in an article discussing the factors involved in the use of single-core cables for telephony.

In connection with the plans for the Key West-Havana cables, a theoretical investigation[5] was made to determine how the resistance of the sea return is affected by the dimensions and construction of the cables and how it varies with frequency. This work in addition to giving a basis for investigating the effect of the dimensions of the cable and of the number and size of armor wires on the resistance of the sea return, made possible also the determination of the effect of a method proposed for reducing the losses in the sea return by providing a path of low resistance for the return current. It has long been the practise, when necessary to protect the insulation from the teredo, a marine borer, to wrap the gutta-percha insulation of submarine cables with a thin tape of brass or copper. This conducting tape suggested the use of a heavy copper tape, which, being just outside of the insulation, would be in the position which the high-frequency return currents would naturally seek to occupy. With this construction the lower frequency currents divide between the sea water, armor wires and the copper tapes, but as the frequency increases the part which returns through the tapes increases until finally for the upper frequencies in the telephone range practically all the current returns through the copper tapes. The resistance of these tapes becomes, therefore, practically the upper limit to the resistance of the return path. By making this path sufficiently low in resistance, it is possible to increase materially the efficiency of the cable. Furthermore, it is relatively inexpensive to place copper outside of the insulation, the main limitation to the amount being a mechanical one; namely, that as the tapes are made heavier and consequently stiffer, there is danger of damaging the insulation when the cable is bent. It was found that this idea of providing a conductive tape for the return was not new,[6] but investigation failed to show that it had ever been used or that any quantitative information had been published as to its effectiveness. This construction forms practically a concentric cable in which the outside cylinder is in contact with the water. In addition to its beneficial effect on the sea return, it is desirable also in that by reducing the external field of the circuit

3. Fondiller and Martin, "Hysteresis Effects of Varying Superposed Magnetizing Forces" Journal A. I. E. E., February, 1921.

4. Devaux-Charbonnel, *Journal Telegraphique*, May 25 and June 25, 1913.

5. Carson and Gilbert, "Transmission Characteristics of the Submarine Cable." *Journal of the Franklin Institute*, December 1921.

6. British Patent No. 10,313 of 1895, Willoughby Smith and W. P. Granville.

it decreases the induction between adjacent cables and also tends to decrease the effect of extraneous electrical disturbances.

In order to get directly experimental information regarding the interference and the effect of the sea return on submarine cables, permission was obtained from the British Columbia Telephone Company to make tests on their cable to the island of Vancouver,[7] from the Western Union Telegraph Company to test their cables landing at Key West from Cuba, and from the United States Government to make measurements on a cable from Key West to Sand Key, a small island about 8 miles (14.8 km.) from Key West on which are located a lighthouse and a weather bureau station.

The Vancouver cable is a four-core continuously loaded gutta-percha cable with a brass protective tape wound around the group of cores. Measurements were made of the sea return for grounded circuits, of the interference on grounded circuits and of the induction from a telegraph cable of the Canadian Pacific Railroad which parallels the telephone cable. In addition, tests were made to get some indication of the cross-talk which might be expected between the physical and superposed circuits in such a cable and of the regularity of the impedance in a continuously loaded cable. Tests were also made of the interaction between currents of telegraph and telephone frequencies. The superposition in the iron wire loading of the fields of these two currents has been found[8] to increase the attenuation of the circuit for telephone currents. This has been called the "flutter" effect.

The Western Union cables are single-core gutta-percha-insulated non-loaded cables with protective metal tapes. Measurements were made of the interference on the cables and also of the cross-talk between the cables.

The Sand Key cable is a four-core non-loaded rubber-insulated telephone cable which has no protective metal tape. On this cable the sea return effect and the interference were measured.

It should be noted that measurements cannot be made directly of the sea return resistance for telephone frequencies. The resistance of the grounded circuits was determined from measurements of the impedance of the circuit, from measurements of the attenuation and from such data regarding the constants of the cables as could be obtained from tests on short pieces. The resistance of the conductor itself was obtained from tests on metallic circuits. For the Vancouver cable, this included the effect of the loading on the resistance of the circuit for alternating currents.

The magnitude of the sea return effect so determined checked closely the theoretical computations. In the case of the Vancouver cable this check involved taking into account the thin protective brass tape which had an appreciable effect. It was found also that the interference both from natural sources and from power systems would not be serious with amplifications even larger than those required on the Key West-Havana telephone cables. The tests for cross-talk between the cables at Vancouver which were about a mile (1.86 km.) apart for their length of about thirty miles (55.6 km.) gave no indication of induction from one cable to the other. The test on the Western Union cables which all terminated in the same hut at Key West gave a maximum cross-talk of less than 10 units at 1000 cycles (a unit of cross-talk being a ratio of current in the disturbed circuit to current in the disturbing circuit of 1 to 1,000,000). The flutter tests on the Vancouver cables showed that if the currents of the several channels were kept within reasonable limits, this effect should not cause trouble even for longer cables.

The results of these tests removed any question of serious interference and cross-talk with single-core cables under the proposed conditions. They verified the serious effects of the sea return resistance, but by providing a check on the theoretical work, gave assurance that this could be applied in estimating the effect of employing heavy copper tapes to limit the resistance of the sea return.

Cable Design

Conductor. To provide flexibility and security against breakage, it is customary to make the central conductor of a submarine cable not of a single solid wire but of a central wire surrounded either by a layer of copper wires or by a layer of thin copper tapes. In the present case the latter construction was used because of the smoother surface it provides for the loading wires. It also tends to give somewhat lower resistance and capacity for a given weight of copper. The actual conductor consists of a round copper wire 0.115 inch (2.92 mm.) in diameter surrounded by five copper tapes each 0.077 inch (1.96 mm.) wide and 0.0125 inch (0.32 mm.) thick. This conductor has a weight of 350 lb. (159 kg.) per nautical mile (1.86 km.). It was specified to have a resistance not to exceed 3.52 ohms per nautical mile at 75 deg. fahr. (24 deg. cent.)

Loading. The cable is loaded with a single close layer of iron wire 0.008 inch (0.2 mm.) in diameter applied directly upon the central copper conductor. There are approximately 120 turns of this loading wire per inch length of the conductor. While an equally efficient cable for the transmission of telephone frequencies could have been produced at a lower cost by using a smaller conductor with heavier loading in the form of more layers or thicker iron wire or both, the requirements of the carrier telegraph made the lighter loading more desirable, as will be shown later.

Insulation. The loaded conductor is treated with Chatterton's compound and insulated with gutta-percha mixture applied in three layers, thus forming a

7. La Belle and Crim, "The Gulf of Georgia Submarine Telephone Cable." A. I. E. E. Trans., 1913.

8. Fondiller and Martin, loc. cit.

"core." The amount of this insulating material is 315 lb. (143 kg.) per nautical mile which provides a wall thickness of approximately 0.135 inch (3.4 mm.). Because of the loading and the high frequencies for which the cable is used, low alternating-current conductance was specified for the dielectric, requiring the use of a special gutta-percha mixture.

Return Conductor. As already stated copper tapes were applied to the outside of the core to diminish the losses caused by the sea return. In the actual construction a copper tape 1 inch (2.54 cm.) wide and 0.004 inch (0.1 mm.) thick is applied directly upon the core with short enough lay to provide safe overlap. Upon this tape are laid two heavier copper tapes, each 0.625 inch (1.59 cm.) wide and 0.022 in. (0.56 mm.) thick. These two heavier tapes are applied with a much longer lay, and are laid side by side with the edges not quite touching. The entire system of copper tapes, weighing approximately 850 pounds (390 kg.) per nautical mile, provides a return conductor with a direct-current resistance in the laid cables of approximately 1.65 ohms per nautical mile. The thin tape first applied directly on the core furnishes also the protection against injury of the core by the teredo.

Sea Grounds. The main core with loaded central conductor and uninsulated return conductor, as described above, extends through the entire length of cable. In submarine telegraph cables it is the practise, in cases where it is especially important to reduce as much as possible all disturbances from outside sources, to construct portions of the cable near the ends with two cores so that the return part of the circuit is carried some distance out to sea before being connected to ground. In accordance with this practise, portions of each end of these cables were made with such two-core construction. In these portions the return or sea ground core has the same central conductor as the main core, no loading iron, the same amount of insulating material per unit length, and the thin protective copper tape but no heavy copper tapes. At the outer end of each of these sea ground cores its conductor is connected by electric welding to the conductive copper tape on the main core.

Armoring. The armoring protects the core and gives tensile strength to the cable to permit its being handled for laying and for subsequent lifting in case of repairs. As is usual, the size and number of armor wires are adapted to the location, taking into account such matters as depth, nature of bottom and water currents. The shore end portions, where because of relatively shallow water the cable is most likely to be injured, have the heaviest armor wire, which in this case has a diameter of 0.3 inch (7.6 mm.). The portions of the cable lying in the deepest water are armored with wire having a diameter of 0.104 inch (2.6 mm.). Intermediate portions of the cable have armor wires whose diameter is 0.192 inch (4.9 mm.). The 0.104 inch armor wire for the deep sea cable is a springy steel wire intended to give great tensile strength to the cable, while the heavier armor wire for the shore end and intermediate cable in shallower water consists of soft iron. The armor wire in all types of the cable is galvanized and is coated with preservative compound before being applied to the cable. The wires for the deep sea portions, in addition to being compounded, are individually wrapped with an impregnated fabric tape, which serves the double purpose of protecting the wire and making the cable more flexible by keeping the armor wires separated.

Before the armor wires are applied, the core or cores are served with tanned jute yarn applied in one or more layers to form a bedding for the armor wires. In those portions of the shore end cable which have two cores, these are laid up together with a relatively long lay and with tanned jute in the interstices between the two cores, before applying the jute bedding for the armor wire.

TABLE I

LENGTHS OF THE SEVERAL TYPES IN EACH CABLE

Type of Cable	Armoring or Sheathing	Length—Nautical Miles*		
		Western Cable	Center Cable	Eastern Cable
	Key West End			
Shore end twin with lead-covered cores...	17 No. 1 (0.300 inch) wires	0.2	0.2	0.2
Shore end twin plain cores...............	15 No. 1 (0.300 inch) wires	3.0	3.0	3.0
Shore end single.......	10 No. 1 (0.300 inch) wires	14.0	9.5	10.5
Intermediate single....	14 Nos. 6 (0.192 inch) wires	10.5	10.5	9.5
Deep sea single........	20 No. 12 (0.104 inch) wires (taped)	73.3	74.5	79.2
Intermediate single....	14 No. 6 (0.192 inch) wires	1.5	1.0	1.0
Shore end twin plain cores...............	15 No. 1 (0.300 inch) wires	1.8	1.3	1.3
Shore end twin with lead-covered cores...	17 No. 1 (0.300 inch) wires	0.2	0.2	0.2
	Havana End			
Total................		104.5	100.2	104.9

*A nautical mile is 6087 feet (1855 meters).

The total length of cable laid on each of the three routes as given is somewhat greater than the distance along the route in order to provide slack.

In the extreme shore ends a short length is made with each core covered with a close fitting tube of lead to protect it from light and air, which would tend to cause deterioration of the gutta-percha in those portions which may extend out of the water.

The lengths of the several types differ somewhat in the three cables because of differences in the routes. In a general way the heaviest type of armoring extends from the shore to a point where the depth is approximately 100 fathoms (183 meters) and the intermediate type from this point to one where the depth is approximately 250 or 300 fathoms (457 to 549 meters), with the deep sea type in all the deeper parts. This arrangement carries the heavily armored cable much farther

out from the Key West end than from the Havana end because of the much more gradual increase of depth of water at the Key West end. For the same reason the two-core or twin cable, which provides the return core for the sea ground, is carried out considerably farther at the Key West end. The approximate length of each type actually installed and the sequence of types are given for each cable in Table I.

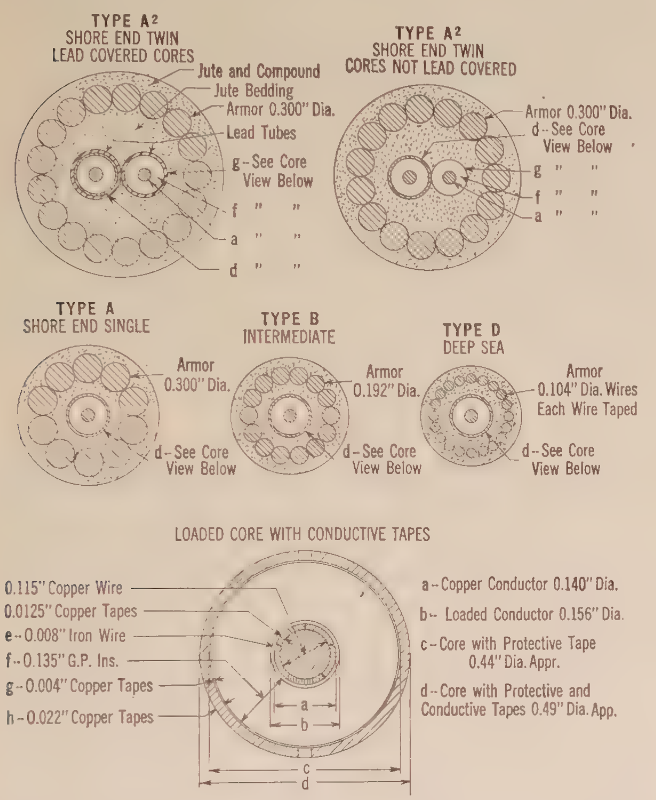


Fig. 2—Cross-Sections of the Various Types of Cable Used

Some of the principal details of the design of the several types of cable with their relative dimensions are shown in the diagrams of Fig. 2. A photograph of specimens showing the appearance of the cables and some details of their construction is reproduced in Fig. 3. The over-all diameter of the largest shore end cable is approximately 2.4 inches (6.1 cm.) and that of the deep sea type approximately 1.2 inch (3.0 cm.).

Cable Manufacture and Testing

The cables were manufactured and laid by the Telegraph Construction and Maintenance Company, Limited, of London.

Since the mechanical structure of these cables is in most respects similar to that of gutta-percha-insulated submarine telegraph cables, the manufacture was in the main carried on along the lines followed in making such cables. Briefly, this process is as follows: The central conductor is made by stranding around a copper wire a layer of finer copper wires or a layer of thin copper tapes. This conductor is then covered with the gutta-percha insulating material, generally applied in two or three layers to diminish the chance of a defect extending through the insulating envelope. Before applying the gutta-percha, the conductor is treated with a thin coating of Chatterton's compound, to fill the interstices in the conductor and to increase the adhesion between the conductor and the gutta-percha. The insulated conductor so formed is known as a "core" and is manufactured in lengths generally ranging from 1½ to 3 nautical miles (2.8 to 5.6 km.), depending upon the weight of the core. In general it is necessary to manufacture heavy core in shorter lengths than light core. After the necessary inspection and tests the core lengths are served with tanned jute yarn, in one or more layers to form a bedding for the armor wires. In case the cable is to be protected against the teredo, the core, before being served with the jute bedding, is covered with a close overlapping layer of metal tape (generally brass). Either before or after being served with the jute bedding, the individual cores are joined together to form longer lengths. They then pass to the armoring or closing machine, which applies the armor wires. The galvanized armor wires, before being used, are coated with preservative compound and the armoring machine applies over the outside of the armor wires wrappings of tarred jute yarn or of a heavy burlap-like fabric known as "Hessian" band. Between the armor wires and these outer wrappings, as well as between and over the several wrappings,

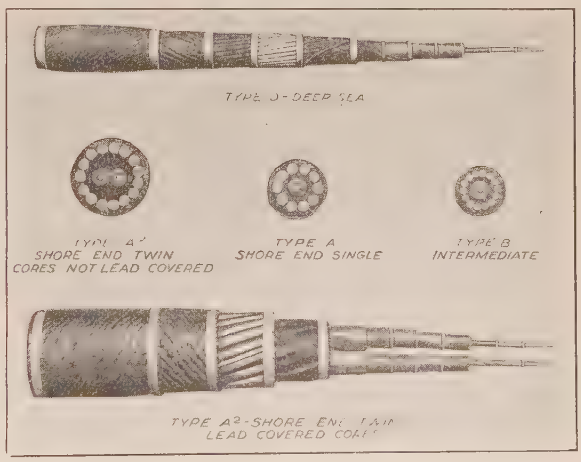


Fig. 3—Specimens of the Various Types of Cable Used

coatings of preservative compound are applied. From the armoring machine the cable is laid directly into the factory cable tanks, where it is treated with whitewash to prevent sticking, and where it is then kept submerged in water until it is transferred to similar tanks in the cable ship, for transport and laying.

In the splicing of two lengths of cable, either at the factory or on the cable ship, a core joint is first made to unite the conductor and its insulation in the two portions of cable. Over this the jute bedding is then reapplied by hand, and finally the armor wires which had previously been opened up and laid aside, are

laid back in such a way that the armor wire from one of the two pieces extends for a length of 15 feet (4.6 m.) or more over the armor wire of the other part. After laying the armor wire in place the splice is served with several tight bindings of galvanized iron wire and the whole covered by a continuous close binding of tarred yarn.

In the manufacture of these cables the application of the iron loading wire to the conductor added an operation which, because of its relative slowness, largely determined the length of time required for manufacture. The heavy conductive copper tapes which are applied to the outside of the core could, because of their weight, be handled only in limited lengths of something like 200 feet (61 m.). Successive portions of this tape were joined together by welds. A soldering or brazing operation would have required the insertion of a dissimilar metal, which would increase the tendency to electrolytic corrosion when in contact with sea water.

The cable in process of manufacture was subjected to the usual visual and manual inspections and electrical tests. The core was manufactured in individual lengths of approximately two nautical miles (3.7 km.) each. These individual core lengths, after 14 days' submersion in water, were tested at a temperature of 75 deg. fahr. for d-c. conductor resistance, insulation resistance and capacity. During the process of jute serving and armoring frequent electrical tests were made so that if any injury or fault should develop it could be detected and the defective part removed or repaired. Measurements of d-c. conductor resistance, insulation resistance and capacity were again made on the completed cable at various times during and after the manufacture, the loading upon shipboard and during the transport and laying of the cable.

In addition to these tests, which are customary for all gutta-percha-insulated submarine cables, additional measurements were made on the present cables. The inductance and capacity of each length of core were measured by alternating-current methods. A large number of short lengths of core selected so as to represent all parts of the cable were measured for capacity and conductance at 1000 cycles per second and at 75 deg. fahr. It was found that the capacity as measured by a direct-current galvanometer method agreed within one per cent with the capacity obtained by measurements with alternating current of 50 cycles or 1000 cycles per second. Table II gives the average values per nautical mile of the several electrical constants as measured on the cores at a temperature of 75 deg. fahr. 14 days after manufacture.

TABLE II

Direct-Current resistance	3.32 ohms
" " capacity	0.311 microfarads
" " insulation resistance after one minute electrification	920 megohms
1000-Cycle inductance	4.35 milhenrys
" " conductance	12.8 micromhos

The corresponding values for the completed cable when laid are in some respects materially different. The insulation resistance is higher in the laid cables because it increased both with age and with the lower temperature at the sea bottom. The 1000-cycle conductance decreased with age but increased with the lower temperature—these two effects thus tending to offset one another. The inductance for the comp eted cable corresponds to that of a central loaded conductor with a concentric cylindrical return circuit, while the inductance measured on the individual cores was that of a gutta-percha-insulated loaded conductor in bifilar form. The conductor resistance is, of course, different because of the lower temperature of the laid cables.

These extensive measurements were made to obtain data regarding the electrical properties of the cable and of the individual lengths of core. The data on the core lengths were used to determine their best sequence, in order to make the impedance at the ends of the cable as uniform as possible over the range of frequencies required for telephone transmission.

Cable Laying

The cable ship arrived at Key West February 7, 1921, and after certain preliminaries such as securing barges and tugs and making the necessary arrangements with the Government authorities proceeded with the laying operations.

Where the water was deep enough the cables were laid directly from the cable ship which brought them from the cable factory to the Florida Straits. In shallower water the cables were laid from a barge or lighter towed by a tug. The actual sequence of laying each cable was as follows: First a length of approximately 6 or 8 miles (11 or 15 km.) was laid from a barge at the Key West end. The barge with its length of cable was brought as near as possible to the Key West cable hut. The extreme Key West end of the cable was pulled from the barge to the shore, laid in a trench on the beach and terminated in the hut. To facilitate this landing the portion between the barge and the hut was supported at intervals by empty casks, to which the cable was tied by ropes, and thus floated in the water. After the landing of the shore end, the main portion of this cable section remaining on the barge, its length having been suitably chosen, was laid outward to a point having a depth sufficient for the cable ship. At this point the end was sealed and dropped to the bottom with an anchor attached to a marking bouy. Later this cable end was picked up by the cable ship and spliced to the next length, which was then laid by the ship from this point to the end of the intermediate type of cable, which as already stated reached to a point where the depth of water was about 250 or 300 fathoms (457 or 549 meters). Again the end was sealed and laid overboard with an anchor and a marking bouy. Next a short length of shore end cable was laid by barge from the Havana cable hut outward and its end lifted to the ship and there spliced to the main length of cable, which

was then laid by the ship from this point near Havana to the point where the bouy marked the location of the end of the intermediate cable previously dropped. After lifting this bouyed end the final splice was then made on the ship connecting the bouyed end to the main cable on the ship and the work of laying completed by dropping the final splice overboard.

After the completion of the laying of the three cables the final acceptance tests were made at the ends of the cables in the Key West cable hut These tests covered only such measurements as are customary on submarine telegraph cables; *i. e.* measurements of direct-current conductor resistance, direct-current insulation resistance and direct-current capacity. They were intended merely to determ ne these direct-current properties and to insure the electrical integrity of the cables after completion of the laying. The results of these tests are shown in Table III wh ch gives values per nautical mile:

TABLE III

	Western Cable	Center Cable	Eastern Cable
Conductor resistance—ohms	3.13	3.11	3.11
Capacity-microfarads......	0.315	0.316	0.314
Insulation resistance after one minute electrification—meghoms.......	8900	7600	8500

These tests were completed the evening of February 25, 1921, and on February 26, 1921, the surplus and spare cable was delivered into the storage tank at Key West and the cables were formally accepted.

Cable Characteristics

In view of the fact that the return circuit of the single-core cable includes the sea water, the operation of the cables could not be determined accurately until they were laid. The lengths of the laid cables are such that determinations at telephone and carrier frequencies of the primary constants, resistance, inductance, capacity, and conductance can not be made directly. The secondary constants, the impedance and attenuation can be measured and these data together with the results of the tests on short pieces used to estimate the primary constants.

After acceptance, extensive alternating-current measurements were made on the three cables, covering the range from about 100 to 6000 cycles. These tests included determinations of the ratio of the current received at one end of the cable to that sent in at the other and measurements of the impedance at each end of each cable with the far end closed through the characteristic impedance of the cable. From these measurements of the ratio of the 'received" current I_2 to the "sent current I_1, the attenuation constant α per nautical mile of each of the cables was obtained from the relation

$$e^{-L\alpha} = \frac{I_2}{I_1}$$

where L is the length in nautical miles. These values for a range of frequencies are given in Table IV. It is seen that the values for the three cables do not differ materially. The average of the attenuations for the three cables is shown also in Fig. 4.

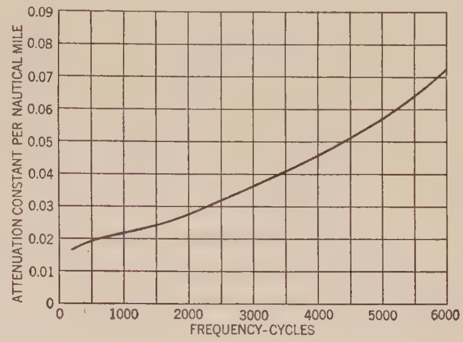


Fig. 4—Average Attenuation Constant of the Cables

The transmission equivalent of the center cable, which is the shortest, is shown in terms of miles of standard cable at 800 cycles (attenuation of one mile of standard cable at 800 cycles is 0.109) in Fig. 5. This figure gives in addition the combined equivalent of the compositing apparatus in the two huts and the land cables at the two ends between the cable huts and the offices, and also the total equivalent of the circuit from the Key West office to the Havana office.

Table V gives the total equivalent of the circuit over the center cable between the two offices and the corresponding current ratios.

The variation of the resistance and reactance components of the impedance of the cable is illustrated in Fig. 6. The deviations of these curves from those that would be obtained if the cable were absolutely uniform throughout its length are under 3 per cent.

From these measurements, from the tests in the factory and from computations, it is possible to estimate fairly closely the constants of the cables. The

TABLE IV
ATTENUATION CONSTANT PER NAUTICAL MILE

Frequency Cycles per sec.	Cables			Average
	Western	Center	Eastern	
200	0.0170	0.0165	0.0168	0.0168
500	0.0196	0.0197	0.0190	0.0194
1000	0.0216	0.0216	0.0216	0.0216
2000	0.0278	0.0278	0.0278	0.0278
3000	0.0357	0.0361	0.0371	0.0363
4000	0.0450	0.0460	0.0470	0.0460
5000	0.0558	0.0574	0.0594	0.0575
6000	0.0710	0.0716	0.0748	0.0725

average of these constants for the three cables is given in Table VI. The conductance is not given for frequencies of 1000 cycles and lower as its effect for this range is so small as to make determination of its value practically impossible under the conditions.

Estimates were also made of the distribution of the resistance in the circuit for a range of frequencies.

TABLE V
TOTAL EQUIVALENT-HAVANA OFFICE TO KEY WEST OFFICE
CENTER CABLE

Frequency Cycles	Equivalent Miles Standard Cable 800 Cycles	Current Ratio
200	19.8	0.116
500	19.4	0.121
1000	20.8	0.104
2000	27.2	0.0516
3000	35.7	0.0204
4000	46.0	0.00664
5000	58.0	0.00180
6000	72.7	0.00036

The curves of Fig. 7 give average values for the three cables of the d-c. conductor resistance, the increase of the conductor resistance with frequency due to skin effect, the resistance of the sea return and the resistance added to the circuit by losses in the loading iron. The larger part contributed by the loading at the higher

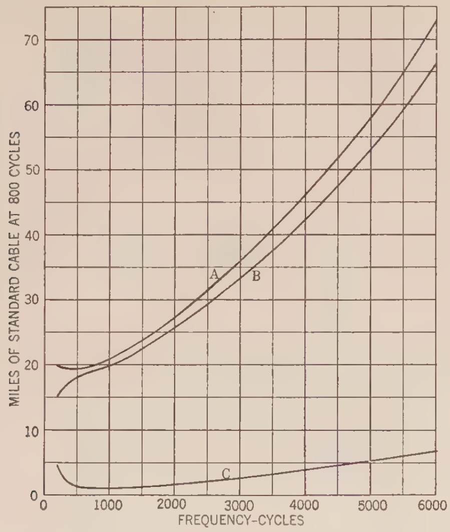


FIG. 5—TRANSMISSION EQUIVALENT OF CIRCUIT OVER CENTER CABLE BETWEEN KEY WEST AND HAVANA TELEPHONE OFFICES

A. Total equivalent between offices.
B. Equivalent of submarine cable.
C. Equivalent of underground cables and apparatus between submarine cables and terminal offices.

frequencies shows why it is desirable to use the light loading where carrier frequencies are to be transmitted. The use of iron wire 0.012 inch in diameter would have increased the resistance added by the loading by about 55 and 90 per cent at 3000 and 5000 cycles respectively

TABLE VI
AVERAGE ELECTRICAL CONSTANTS OF CABLES PER NAUTICAL MILE

	Frequency-Cycles per Second								
	0	200	500	1000	2000	3000	4000	5000	6000
Resistance-ohms	3.12	4.1	4.5	4.8	5.8	7.2	8.7	10.9	13.7
Conductance-micromhos	..	..	..	...	45	90	140	180	230

Capacity—0.31 microfarad
Inductance—0.0041 henry
Effective Permeability of Loading—115

above the values obtained with 0.008-inch wire. These increases in resistance, in spite of the increase in inductance resulting from this change, would have increased the attenuation by 33 and 65 per cent at these frequencies.

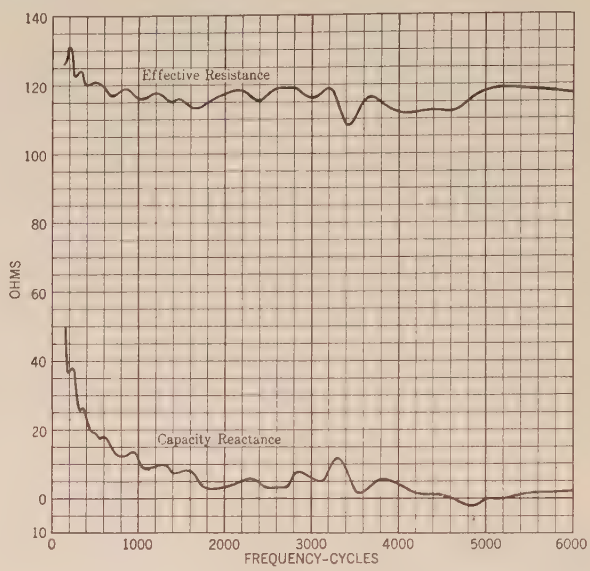


FIG. 6—IMPEDANCE OF EASTERN CABLE AS MEASURED FROM THE KEY WEST TERMINAL

Estimates of the resistance of the sea return which would have been obtained in the deep sea portion of the cable if no copper tapes had been provided give values of 4, 6.5 and 8 ohms per nautical mile at 1000, 3000 and 5000 cycles. The resistance actually obtained with the copper tapes does not exceed 1.7 ohms at 5000 cycles, as shown on the curves of Fig. 7. The greater values would have increased the attenuation

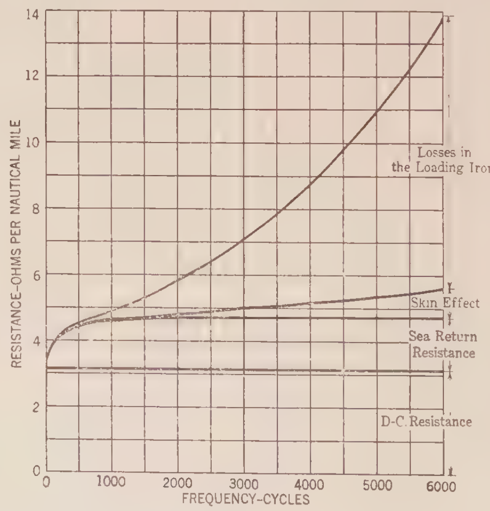


FIG. 7—ANALYSIS OF THE RESISTANCE OF THE CABLE CIRCUIT

by approximately 30 per cent at 1000 cycles and by 50 per cent at the two higher frequencies.

The results of the measurements of the cross-talk obtained at Key West between two adjacent cables is shown in Fig. 8. It will be noted that the cross-

talk between the cables when the connection is made to the copper tapes is less than one per cent of that obtained when the connection is made to the insulated sea ground conductors.

Measurements of the interference on these cables showed this to be practically negligible. As might be expected, the interference of frequencies in the d-c. telegraph range was greater when using the return tape than when using the sea ground. The interference at the telephone and carrier channel frequencies was, however, many times greater when using the sea ground conductors, the interference when using the return tape being so small as to be negligible even with amplifications larger than required for operation. The maximum interference currents obtained with the tape return were less than one microampere and this was largely 180-cycle current, which was probably produced by a harmonic in a power circuit near the terminal.

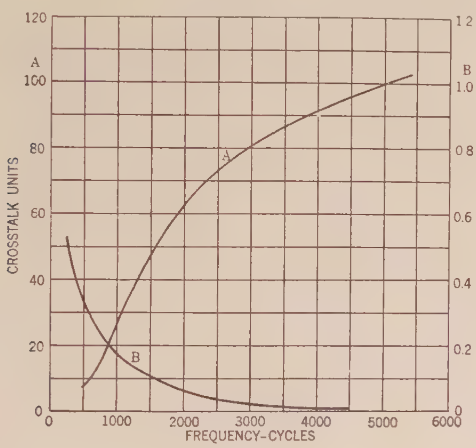


FIG. 8—CROSS-TALK BETWEEN TWO OF THE CABLES
A. Both cables using sea ground.
B. Both cables using copper tape return.

The results of the cross-talk and interference tests confirm the expected operation of the heavy copper tape return, that is, that practically all the current of frequencies in the important part of the telephone range and above would return through the tape. On the same basis the tape acts as a very effective screen against interference currents of these frequencies.

Measurements of the flutter effect between the d-c. telegraph and the telephone channel showed that the passing of the telegraph currents over the cable simultaneously with currents of frequencies in the telephone range, reduced the magnitude of the received telephone current by only a small fraction of one per cent. The maximum value of the d-c. telegraph pulses was about 14 milliamperes. The maximum effect on the carrier telegraph operation of the d-c. telegraph and the telephone together was a reduction of under 3 per cent in the magnitude of the received carrier currents. This was inappreciable in the operation of the carrier system, as the receiving circuit is designed to be saturated with the normal incoming current, so that slight changes in the sent currents or changes in the circuit efficiency have no effect on its output.

Investigation was also made of "modulation" effects in the loading. Where two currents of different frequencies, A and B, are superposed on the circuit and hence have their fields superposed in the iron wire loading, currents of other frequencies are set up in the cable as a result of the non-linear characteristics of the iron. The frequencies of these modulation currents are the sums and differences of the frequencies A and B and of their various harmonics, such as $A \pm B$, $2A \pm 2B$, $2A \pm B$, $A \pm 2B$, $3A \pm 3B$, $3A \pm 2B$, $3A \pm B$, $A \pm 3B$, and so on. The superposition of additional currents of frequencies different from A and B produces of course additional resultant modulation currents.

The even order modulation currents, that is, those of frequencies for which the sums of the coefficients of A and B are even numbers, such as $A \pm B$ and $2A \pm 2B$, are due largely to magnetic bias of the loading and are therefore materially affected by the amount of direct current flowing in the circuit. The odd order terms, such as $2A \pm B$, $A \pm 2B$ and so on, are produced by the non-linear force-flux characteristic of the iron and are less affected by the direct current.

The principal modulation currents found in the work on the cable were those of frequencies $A \pm B$, $2A - B$, $2B - A$, $3A - 2B$, and $3B - 2A$. Others were present but were either so small in magnitude or so high in frequency as to be negligible compared to the above. The measurements of the small modulation currents necessarily involve highly selective circuits, large amplifiers and special circuit arrangements in order to prevent the currents causing the modulation from entering the circuit measuring the modulation currents and also to eliminate the modulation effects in the measuring apparatus itself. For the present arrangement of channels with the 3000-cycle carrier flowing into the cable at Havana and the 3800-cycle carrier at the Key West end the modulation currents produced by the carrier telegraph currents are very small. The $2A$-B term, which is the largest, is only 0.2 microampere. If the two carrier currents are sent into the cable at the same end, however, the modulation currents while still small are appreciable, as shown in Table VII.

TABLE VII

MAGNITUDE OF CARRIER CURRENTS ENTERING SUBMARINE CABLE

A—3000 cyles, 13.6 milliamperes
B—3800 " 18.5 "

MODULATION CURRENTS FROM CABLE

Frequency	Microamperes
A − B, 800 cycles	0.3
A + B, 6800 "	less than 0.1
2A − B, 2200 "	4.7
2B − A, 4600 "	1.3
3A − 2B, 1400 "	1.3
3B − 2A, 5400 "	0.3

While for these arrangements the modulation effects were found to be so small as to cause no serious interference, they may under some conditions become large enough to require consideration, particularly in connection with increasing the number of carrier telegraph channels over the cables. In that case, these modulation currents affect the number of channels, the current levels and the frequencies which can be used. This effect appears not only as noise in the telephone but also as interference between carrier channels. As an illustration of the magnitudes which may be obtained, Fig. 9 shows the 2 *A-B* term for a constant *A* frequency of 2500 cycles with the *B* frequency varying from 3000 to 5000 cycles. The magnitudes of both *A* and *B* are receiving apparatus at that terminal. The balance system consists essentially of a "bridge transformer" and a network of impedance elements designed to simulate the impedance of the line for a range of frequencies. The bridge transformer is a transformer with three windings, from two of which accurately located center taps are brought out. This transformer is thus suitable for providing a Wheatstone bridge circuit in which the two windings having mid-point taps serve as ratio arms. The transmitting amplifier output is connected to the mid-point taps and the receiving amplifier input to the third winding of the transformer. With the balancing network adjusted to have an impedance equal to that of the line, the transmitting

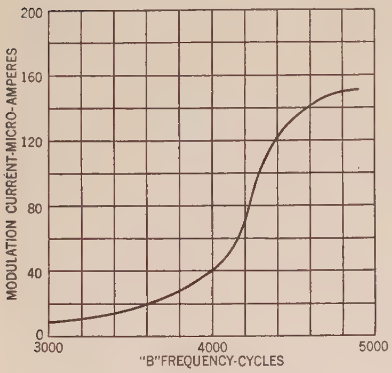


Fig. 9—Modulation Effect in Cables

Current of 2 $A-B$ frequency for A frequency = 2500 cycles. Current of both A and B frequencies = 30 milliamperes into submarine cable.

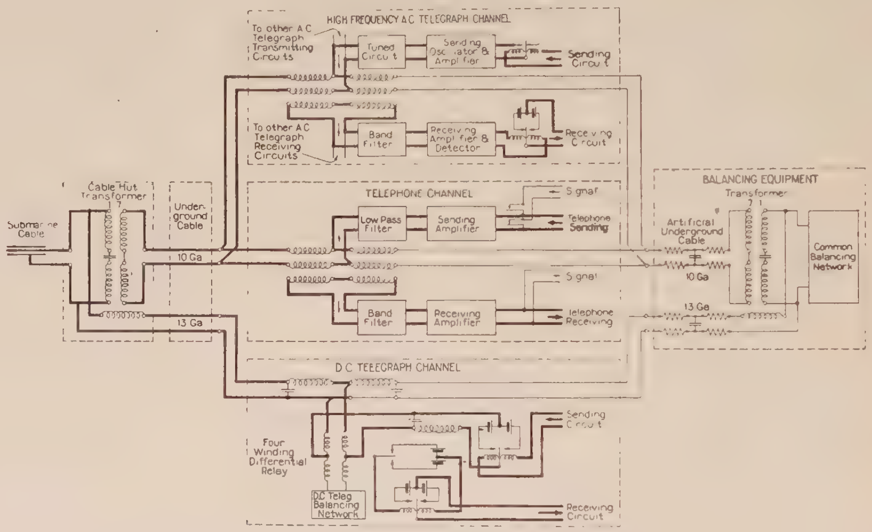


Fig. 10—Compositing Arrangement at Terminals

30 milliamperes into the submarine cable at the same end, the modulation currents being measured also at that end. It is seen that for the lower frequency values of 2 *A-B*, the magnitudes are comparable with those of components of the telephone currents on the cable.

Compositing Arrangement at Terminals

For the initial operation over the cables, arrangements were made and apparatus provided for two duplex telegraph channels and a telephone channel over each of the three cables. One of the telegraph channels is furnished by the direct-current system and the other by the carrier-current system using frequencies above the voice range. In addition to the above, a signaling channel required for the operation of the telephone channel uses currents of frequencies in the voice range. It is possible to employ this range since it is not required simultaneously for signaling and talking.

The general method of superposing these channels on the cable and connecting them to the terminal apparatus is shown in Fig. 10. As the channels are required to operate in both directions, the usual balance system is provided for each channel to prevent the currents sent out at one terminal from operating the amplifier does not send current into the receiving amplifier.

Filters or selective circuits are placed in the sending circuits to insure that the outgoing currents of any channel do not contain frequencies which will interfere with the other channels, and in the receiving circuits to admit only those currents in the proper frequency range.

At the cable hut the submarine cable is connected by a 1 to 7 impedance ratio, specially balanced transformer to a two-wire underground cable circuit of No. 10 A. W. G. (diameter 0.102 inch, 2.6 mm.) conductors. Across the cable side of the transformer is bridged a No. 13 A. W. G. (diameter 0.072 inch, 1.8 mm) two-wire circuit for the direct-current telegraph channel. The No. 10 circuit carries the telephone and the carrier telegraph channels to the office. The transformer serves to insulate the grounded submarine cable from the land cable and thus renders the atter less susceptible to interference from power systems. It also steps up the impedance of the cable to meet the impedance of the telephone and carrier channel terminal apparatus and aids in keeping the d-c. te egraph currents out of the higher frequency channels. This latter function

is assisted by the condenser at the mid-point of the cable side of the transformer.

The telephone and carrier apparatus is connected in parallel to the No. 10 A. W. G. underground cable circuit. Each set of equipment contains a bridge transformer which separates the sending and receiving circuits. These two bridge transformers are connected in parallel both to the cable and to the common balancing network so that the sending circuit of either channel will not send current into the receiving circuit of the other channel. The sending channels are not so balanced against each other, but since each contains a filter or tuned circuit which presents high impedance to currents from the other sending circuit, little current flows from one sending circuit to the other. The receiving side of the telephone is protected by balance against the sending side of the telephone and by both balance and selectivity against the sending side of the carrier channel.

The d-c. telegraph channel is also in parallel with the telephone channel but is connected to it at points different from the carrier channel. The inductance coils and condensers in the d-c. channel constitute a low-pass filter which transmits frequencies from zero to about eighty cycles. This channel has one branching arrangement which is designed so that the receiving circuits of the higher frequency channels are balanced against both the outgoing telegraph currents and the disturbances produced in the relay windings by the operation of the relay armature under the actuation of the received signals. It has also the second branching arrangement in the windings of the receiving relay, to separate the sending and receiving telegraph circuits. This requires the second balancing network which is connected with this relay.

It will be noted that associated with the main balancing network shown in the right of Fig. 10 is a duplicate of all the apparatus and circuits between the terminal apparatus and the submarine cable. The balancing network itself is adjusted to simulate the impedance of the submarine cable over the range of frequencies required for the operation of the telephone and telegraph channels, particular attention being paid to have it meet this impedance for the range of the telephone channel. Because of the degree of uniformity obtained in the impedance of the cables, it was possible to get a very good simulation with a simple network of three impedance elements. If the cables had been less uniform it might have been necessary to employ a multi-section artificial cable such as is used with long submarine telegraph cables. The balancing transformer and artificial underground cable are adjusted to match the impedances of the corresponding elements in the cable circuit. By this means, it is possible to obtain a balance at the terminals of the bridge transformers which for any frequency in the telephone range is within 3 per cent of being perfect, thus making it possible to use high amplifications with this channel. The degree of balance is only slightly poorer in the carrier telegraph range.

Since the attenuation in the range available for carrier telegraph use is greater than that in the telephone range and the amplifications therefore necessarily larger, the land-line carrier telegraph practise was followed in not relying entirely upon the balance to prevent interference between the outgoing and incoming carrier currents but in using different frequencies in the two directions with the selective circuit and filter in the sending and receiving branches tuned respectively to these different frequencies. For operation from Havana to Key West a carrier frequency of 3000 cycles is used and for the opposite direction a carrier frequency of 3800 cycles.

The arrangement of the terminal apparatus in the cable hut is shown in Fig. 11. Each of the submarine cables is terminated in one of the boxes at the left, which are water-proof. The submarine cable enters the box from below, the two cores entering through separate bushings. The underground cable circuits from the office are brought into the boxes from above. Cables also lead from these boxes to the pots at the right which contain the transformers, condensers and inductance coils located at the hut. A tie cable enters all the boxes from below to make possible cross-connection of the circuits and apparatus.

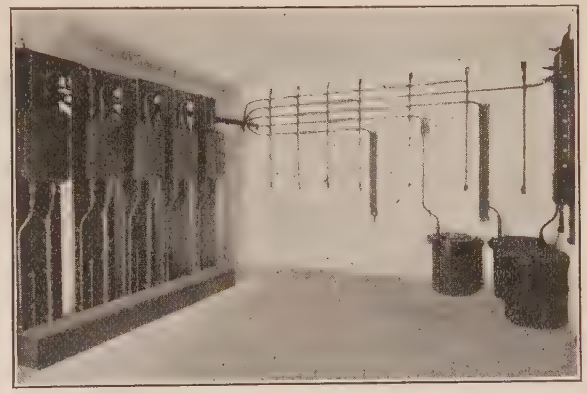


FIG. 11—APPARATUS IN CABLE HUT

TERMINAL EQUIPMENT

Amplifiers and signaling apparatus for the telephone circuits and terminal apparatus for the telegraph and carrier telegraph channels are provided for each cable at the terminal offices in Havana and Key West. Although these terminal units in general resemble those developed for similar uses on land-line telephone and telegraph circuits, they differ in many respects because of the high attenuation of the submarine cables and the different methods of operation required on these circuits.

The general theory and operation of telephone repeaters[9], carrier telegraph apparatus[10] and vacuum

9. Gherardi and Jewett, loc. cit.

10. Colpitts and Blackwell, loc. cit.

tubes[11] have been described in various publications. Those features in which the cable apparatus is similar to earlier types will not be discussed here in detail.

The terminal apparatus was designed, manufactured and partly installed before the laying of the cables, in order that service might be given as soon as possible after they were laid. The design of the apparatus was based on the estimated characteristics of the cables

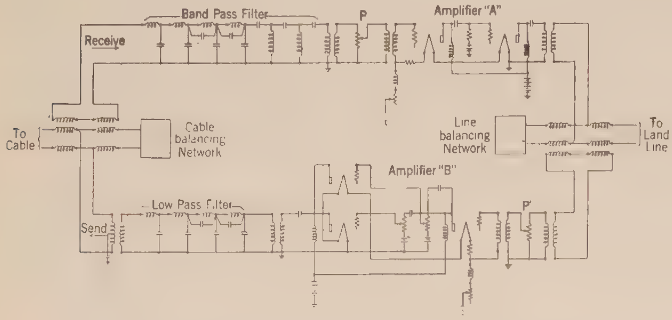


Fig. 12—Circuit of Telephone Repeater

but in order to provide for satisfactory operation, in case the attenuation and interference should exceed the expected values, the terminal apparatus was made adjustable over a wide range of amplifications and current levels.

Telephone Circuit

The telephone channels of the cables are connected to the land lines through bridge transformers and amplifiers as shown in Fig. 12. The third winding of each bridge transformer is connected through an amplifier to the center points of the line windings of the other bridge tranformer, thus forming the two-way, two-amplifier repeater circuit generally called a "22-type" circuit[12]. Since a close and constant balance has been secured between the cable and its network, as pointed out above, the repeater may be worked with large gains[13] even when the balance between the land line and its network is not close. Such is the case in terminating connections where the land end of the repeater is connected through the toll switchboard to subscribers' lines, as in calls to or from subscribers in Havana or Key West, without intervening toll lines of considerable length which could be balanced more closely.

Networks are provided to balance the average subscribers' lines as well as possible. When the repeater is to be connected to land lines of considerable length, networks of the general character described in an earlier paper[14], which provide a better balance for these lines, are used. Such networks are provided for use with the circuits extending north from Key West and also for use with the toll circuits in Cuba.

The repeaters combine the operating characteristics of "through-line" and "cord-circuit" repeaters. A through-line repeater is one which is permanently connected in a toll line, the whole forming a through-line circuit, no part of which is under the control of an operator at the repeater station. In a cord-circuit repeater the two line ends of the repeater circuit appear at the toll switchboard as plugs and this repeater cord circuit may be used to connect toll lines which terminate in jacks in the switchboard. Such a repeater is arranged so that the gain can be adjusted by the toll operator to the value specified for the circuits which it is used to connect. In the Key West and Havana repeaters the cable bridge transformers, the cable balancing networks and the amplifiers are permanently connected to the cables, the repeaters being thus through-line in character on the cable side. The repeaters at Key West on the through circuits are permanently connected to the land lines and their balancing networks, with certain arrangements for patching to be noted below. Such circuits are shown schematically in heavy lines in the upper part of Fig. 13. At Havana, and at Key West on the one circuit terminated there, the land sides of the repeaters terminate in the switchboard, so that these repeaters have some of the features of cord-circuit repeaters. These so-called "terminating connections" are shown in sche-

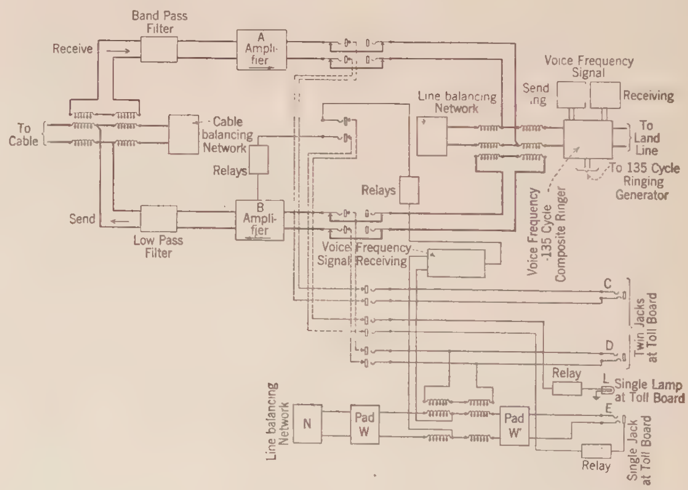


Fig. 13—Circuit of Through Line Telephone Repeater

matic form in Fig. 14. In the terminating as well as in the through-line circuits, the gains of the amplifiers are adjusted by means of the potentiometers P and P' shown in Fig. 12. These are set at the proper values by the repeater attendant. The control at the switchboard of the effective gains of the terminating repeaters is obtained by means of artificial lines or pads on the

11. Van der Bijl, "The Thermionic Vacuum Tube and its Applications." McGraw-Hill Company, New York.

12. Gherardi and Jewett, loc. cit.

13. The term "gain" is extensively used in telephone and carrier practise to indicate amplification and is generally expressed in terms of the number of miles of standard cable, the attenuation of which it will just neutralize.

14. Gherardi and Jewett, loc. cit.

line and network sides of the bridge transformers H and H' as shown in the lower part of Fig. 14.

In the terminating circuits, the land side of the repeater appears at the switchboard in both a single-jack and a twin-jack termination, as shown in Fig. 14. The single-jack termination is used for connections to local subscribers' loops and the twin-jack arrangement for connection to land toll lines. A call coming

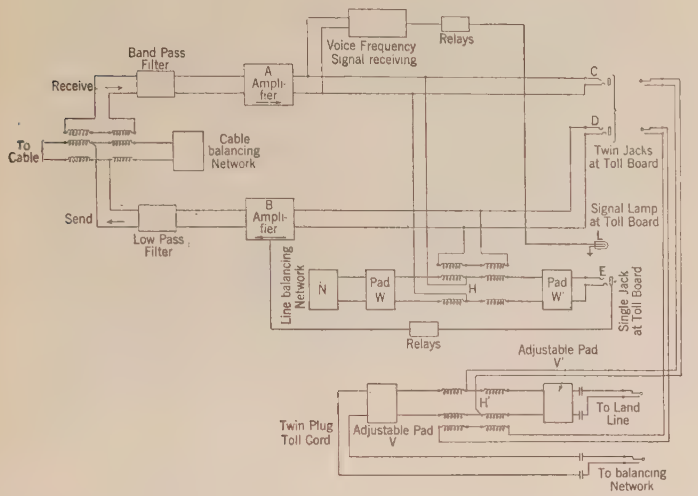


Fig. 14—Circuit of Terminating Telephone Repeater

over the cable, indicated by the lighting of the signal lamp L, is answered with a single-plug toll cord, the plug being inserted in the jack E. If the call is intended for a local subscriber, the other end of the cord is plugged directly into the local circuit at the switchboard. This circuit is balanced by a network N designed to balance the average local connection. When the circuit is not in use the net work N is disconnected and the two equal pads W and W' preserve the proper impedance balance on the two sides of the bridge transformer H, so that singing in the repeater circuit is prevented. The insertion of the cord-circuit plug in the single jack E operates a relay which connects the network N in place. When connection to the subscriber's instrument has been completed, the current from the central battery through his transmitter operates a train of relays which reduces the transmission loss introduced by the pads. The same change in the pads is produced when the operator, by throwing her talking key, causes current to pass through her transmitter. If the call is routed to a toll line, the connection is made by the insertion of a "twin-plug toll cord" in jacks C and D, which disconnects the single jack circuit automatically. The twin plug at the other end of the cord is inserted in the jacks connected to the desired toll line and its balancing network. The circuit of this twin plug toll cord is shown schematically in the lower part of Fig. 14. In this case the operator may control the effective gain of the repeater by a key which changes the number of sections in the adjustable pads V and V'.

In through-line use of the repeaters both amplifiers are continuously supplied with filament current and are maintained in operating condition. In cord-circuit or terminating use the amplifier which receives from the cable is kept in operating condition in order that signals may be received. When a connection is made through either the single- or double-jack circuits, relays are operated which cause current to be supplied to the filaments of the sending amplifier. No current is supplied to this filament circuit except when a connection is established.

In view of the fact that it may sometimes be desired to terminate temporarily at the Key West switchboard any one of the through-line circuits, the repeater circuits have been arranged to facilitate this. It will be noted in Fig. 13 that the through-line circuits pass through a group of jacks. These are located in the "jack panel," a unit in which are terminated all the principal circuits associated with the cable. When the connections indicated by the dotted lines are made the resulting circuit is the same as that of Fig. 14.

In order to protect the telephone apparatus against interference due to the telegraph channels, a filter system is connected in the telephone circuit between each amplifier and the cable bridge transformer. The filter in the receiving branch (Fig. 12) freely passes the range of frequencies (250 cycles to 2300 cycles) assigned to the telephone channel and greatly attenuates currents of all other frequencies. The filter in the send-

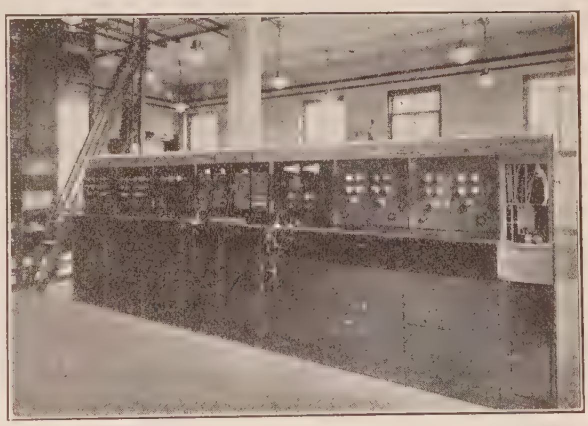


Fig. 15—Telephone Repeater Panels, Jack Panel and Testing panels

ing branch prevents the passage of currents of frequencies which would interfere with the carrier telegraph channel.

The amplifiers, filters and other equipment of each repeater are mounted in a unit panel. These, together with the panels containing the terminal equipment associated with the other communication channels, are arranged in a double row in each terminal office. One of these rows is shown in Fig. 15. Four of the panels, two at each end, are repeater units, three of these being associated with the three cables. Owing

to the importance of these circuits a spare unit has been provided to insure against interruption of service.

Signaling Systems

The signals for the telephone channels are transmitted over the cables by a "voice-frequency" signaling system, which involves the generation, transmission and reception of an alternating current, the frequency of which changes abruptly from 950 cycles to 1300 cycles and back, this alternation of frequencies taking place

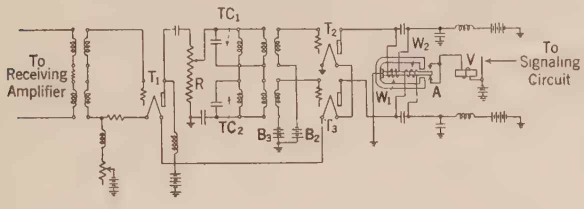


Fig. 16—Receiving Circuit for Voice Frequency Signaling

at the rate of 16 cycles per second. Signals are transmitted over the land lines north from Key West and over the toll lines terminating at Havana by means of the usual 135- and 16-cycle currents.

By means of a ringing key in the toll cord circuit, the operator at one end of the cable causes the voice-frequency current described above to be sent out by the signaling oscillator, a vacuum-tube oscillator of the usual type arranged so that the capacity in the oscillating circuit is changed 32 times a second. This sends out alternately currents of the two different frequencies through the sending amplifier B (Fig. 14) to the cable. At the other end of the cable these currents flow into the receiving side of the repeater and through the amplifier A. If the telephone circuit is terminated at this point, part of the amplified signaling current passes into the receiving circuit for voice-frequency signals as can be seen from Fig. 14.

The details of the voice-frequency signal receiving circuit are shown in Fig. 16. The input impedance of this circuit is high so as to produce no appreciable loss in the telephone transmission circuit across which it is connected. The incoming signaling currents are amplified by the tube T_1, from which they pass into the high resistance R. Connected in series across this resistance are two tuned circuits $T\,C_1$ and $T\,C_2$, of which one is tuned to 950 cycles and the other to 1300 cycles. Each tuned circuit is connected through a transformer to the input side of a vacuum-tube rectifier. The grids of the tubes T_2 and T_3 are made just sufficiently negative by means of the batteries B_2 and B_3 so that there is normally no current flowing in the plate circuits of the tubes. The tubes thus function as detectors of incoming currents. When 950-cycle current is impressed on the circuit TC_1 a voltage is applied to the grid of tube T_2 causing current to flow through the relay winding W_1. The next instant rectified 1300-cycle current passes through winding W_2. The armature A of the polarized relay then vibrates back and forth at the rate of 32 times a second, thereby interrupting the current through the relay V. The armature of this relay therefore falls back, lighting the signal lamp L (Fig. 14) at the switchboard.

In the through-line circuits at Key West, such as the Havana-New York circuit, as shown in Fig. 13, the voice-frequency signaling current coming from the cable causes 135-cycle signaling current to be sent out automatically on the north-bound land line by a special type of "composite ringer" indicated in the upper right-hand part of this figure. The voice frequencies are received by a circuit similar to that just described and operate a relay which connects a generator of 135-cycle current to the land toll line, thus sending out this type of signaling current to call the distant operator. In through-line calls from the north 135-cycle current is sent over the land toll line to Key West. Here it enters the composite ringer and operates the voice-frequency sending set which puts on the cable the voice-frequency currents described above. These currents are received at the Havana toll office in the circuits shown in Figs. 14 and 16 and cause the operation of the signal lamp L at the toll board.

The receiving circuit for voice-frequency signals which is used in the case of terminating connections is included in the repeater unit. The composite ringers, which in the case of through-line circuits effect the

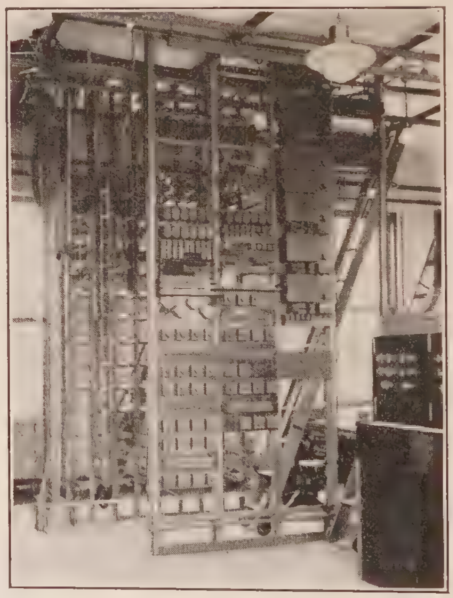


Fig. 17—Relay Rack Containing Signaling Oscillators and Power Control Circuits

change from voice-frequency signaling on the cables to 135-cycle signaling on the land lines, are mounted on the upper right-hand side of the relay rack shown in Fig. 17. Below the composite ringers are two oscillator sets for furnishing the 950- and 1300-cycle currents

for telephone signaling over the cable, one of these being a spare unit.

Carrier Telegraph

A carrier telegraph terminal unit is permanently associated with each cable at both the Key West and Havana Offices. The circuits in the units used at

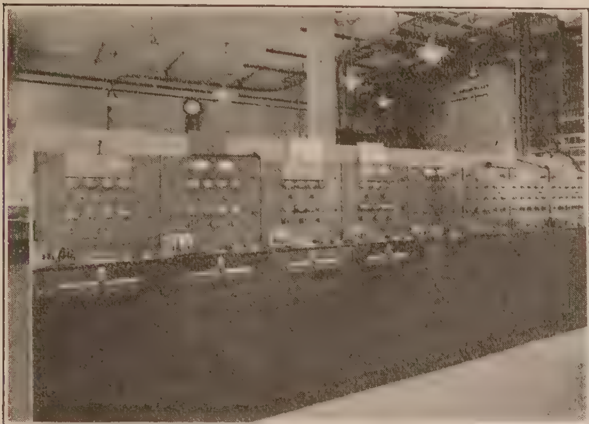


Fig. 18—Carrier Telegraph and D-C. Telegraph Panels

the two terminals are the same, with the exception of the filters in the receiving branches. The carrier panels and their location with respect to the other apparatus are shown in Fig. 18. The four units containing vacuum tubes at the left of the row are the carrier telegraph units, one being a spare unit.

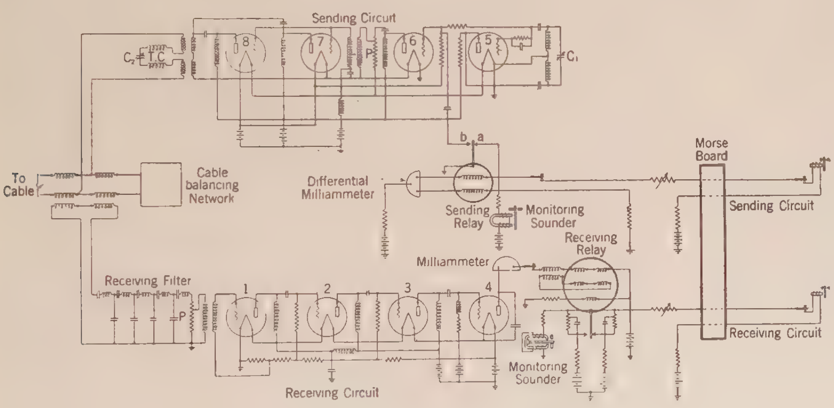


Fig. 19—Carrier Telegraph Circuit

The operation of the carrier telegraph channel may be stated briefly as follows: Direct-current telegraph signals received from a subscriber's loop or other land line, actuate the sending relay in the carrier set, causing the oscillator to send through the cable high-frequency alternating current, interrupted in conformity with the signals. This alternating current enters the carrier receiving circuit at the other cable terminal, is rectified and actuates the receiving relay which sends direct-current telegraph signals into the associated land circuit.

The arrangement of the complete carrier terminal circuit is shown in Fig. 19. The details of carrier telegraph circuits have been described in an earlier paper[15] and only the outstanding features will be mentioned here. The armature of the sending relay[16] is normally held against the contact *a*. Under this condition the oscillator transmits a steady high-frequency current through the amplifier and tuned circuit to the cable. When a "spacing" signal is transmitted over the subscribers' sending loop, the armature of the sending relay moves to contact *b* which shunts the sending amplifier, interrupting the flow of high-frequency alternating current to the cable. A "marking" signal causes this armature to move to contact *a*, thus sending the high-frequency current out upon the cable. The sending relay, therefore, causes the signals transmitted over the land line by direct current to be converted into pulses of alternating current which are sent into the cable.

The outgoing high-frequency current passes through a two-stage amplifier, the last stage of which consists normally of one vacuum tube, either No. 7 or No. 8 in Fig. 19. By means of a switch at the carrier panel, the second tube may be connected in parallel with the first to increase the current. The output of the transmitter is controlled by the interstage potentiometer P. The current from the amplifier passes through a single tuned circuit, $T\,C$. in Fig. 19, which can be accurately tuned to the frequency of the outgoing current by means of the adjustable condenser C_2. The frequency of this current is controlled by the adjustable condenser C_1 in the oscillator circuit.

At the other terminal of the cable the high-frequency alternating current passes through the bridge transformer and receiving filter. Since the attenuation of the cable for the carrier currents is high, the received current is passed through a multi-stage amplifier before it reaches the detector which rectifies it and causes it to operate a sensitive receiving relay. As shown in Fig. 19, the receiving relay retransmits the signals by means of direct current over the subscriber's receiving loop.

The receiving circuit differs from that used in land carrier telegraph systems in the following features: Instead of the usual double tuned circuit

15. Colpitts and Blackwell, loc. cit.

16. For clearness and simplicity in showing the relation of the relays to the telegraph circuits the conventional representation of relays shown in Fig. 19 has been used in this paper. It is to be understood that the windings shown within the circle, act to magnetize the armature which moves back and forth between the poles of a permanent magnet, its position at any time depending upon the polarity of the resultant magnetism in it.

for selecting the proper frequency, a narrow-band, highly selective fixed filter is placed before the amplifier. The gain attainable in the receiving amplifier is much higher than is provided in land-line systems. When less than the full gain is required tube No. 1 can be cut out by means of a key.

The sending and receiving carrier telegraph circuits work directly into subscribers' loops at Havana. In through-line traffic, which is the only type of telegraph traffic now required at Key West, the carrier circuits are arranged to operate standard land-line duplex telegraph sets. The d-c. telegraph circuits from the carrier apparatus pass through jacks in the morse boards for convenience in connecting them to any desired land lines or subscribers' loops.

The arrangement of Fig. 19 is that used for full-duplex operation, that is, when it is desired to transmit messages simultaneously in both directions over the cable. By means of a switch on the carrier panel the circuit may be adapted to half-duplex operation. In this case, messages can be transmitted over the cable in both directions but not simultaneously.

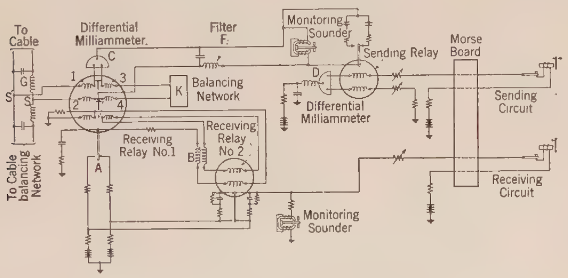


FIG. 20—DIRECT-CURRENT TELEGRAPH CIRCUIT

DIRECT-CURRENT TELEGRAPH

A direct-current telegraph unit is permanently connected at each end of each cable as a repeater of telegraph signals between the submarine cable and a land circuit. The four units at the right of Fig. 18 are the direct-current telegraph panels, one being a spare unit. A schematic diagram of the direct-current telegraph circuit arranged for repeating between the submarine cable and subscriber's loops, is shown in Fig. 20. This figure shows the arrangment for full-duplex operation over the cable.

In this telegraph circuit the separation of the sending and receiving branches is accomplished by the main-line receiving relay, which in its relation to these branches functions like a bridge transformer. Outgoing signals to the cable divide at the points T, half the current passing through coils 1 and 2, and the other half passing through coils 3 and 4. These coils are wound so that with a good balance between the balancing network and the circuits on the opposite side of the relay, the armature A is not actuated by the sending currents. It is evident, however, from Fig. 20 that incoming signals from the cable will produce an additive effect in passing through the relay coils and operate this relay.

The network K balances, for the frequencies involved in direct-current telegraph operation, the impedance between the points S and S'. Reference to Figs. 10 and 20 shows that this includes the two halves of the filter G in parallel, the cable and the cable balancing network as well as the impedance at these frequencies of the telephone and carrier apparatus. The network contains a fixed portion to balance the filter G and an adjustable portion to balance the cable and the associated equipment just mentioned. The balance can be tested by observing the differential milliammeter C (Fig. 20) as signals are transmitted from the sending branch.

Signals coming from the subscriber's sending loop operate the sending relay which acts as a pole-changer to reverse the polarity of the 10-volt battery applied to the cable, in conformity with these signals. The low-pass filters F and G transmit freely all frequencies below about 80 cycles but practically prevent the passage of higher frequencies. They thus allow free passage of those components of the sending currents which are necessary for the operation of this system, but suppress those which might cause interference in the telephone and carrier channels.

A feature of the receiving branch is the tandem connection of receiving relays. Incoming signals from the cable actuate the sensitive receiving relay No. 1 and, as shown, in Fig. 20, the operation of this relay in turn actuates the receiving relay No. 2. The armature of receiving relay No. 2 acts as a pole-changer to transmit signals to the receiving loop. The larger energy available for the operation of this relay enables it to commutate successfully the comparatively heavy currents which are transmitted into the land line. The networks connected between the armature and the contacts of receiving relay No. 2 operate to suppress sparks at break. The purpose of the transformer B is to quicken the action of the receiving relays.

The circuit as shown in Fig. 20 and described above is adapted to working into two loops for a local telegraph subscriber. Apparatus equivalent to a standard duplex set is provided in the telegraph panel so that by throwing a switch, the set may be adapted to duplex operation over a land line. This is the condition at Key West where all the telegraph circuits are continued northward. Switches are also provided in the panel for adapting the circuit to half duplex operation instead of full-duplex operation.

The sending loops, the receiving loops and the 120-volt batteries of the land sides of the direct-current telegraph units are connected through jacks in the standard Morse Boards so that they may be available for cross-connecting or testing.

AUXILIARY EQUIPMENT

A jack panel and two testing panels in each terminal office provide means for testing the circuits and terminal apparatus and for changing their connections. The jack panel contains a system of jacks to which all

circuits are connected and on which are terminated all important pieces of equipment such as amplifiers, filters, networks and bridge transformers. The testing panels contain an oscillator for supplying testing currents of telephone and carrier frequencies, transmission measuring apparatus for testing the telephone repeaters and circuits, apparatus for testing the balance of the networks and lines, thermocouples and meters for measuring the carrier currents, a frequency meter for testing their frequencies and apparatus for testing the efficiency of the carrier terminal sets. In Fig. 15 the jack unit is at the middle of the row of panels, with a testing unit on each side.

A 24-volt storage battery furnishes current for the filament circuits of all the vacuum tubes in the telephone repeaters, carrier telegraph panels, ringer circuits and testing apparatus. Positive and negative 120-volt batteries are provided for the standard duplex sets and for the local circuits of the carrier and direct-current telegraph sets. The positive 120-volt battery also furnishes plate current for all vacuum tubes. Grid potentials for the vacuum tubes are derived from a small capacity 60-volt storage battery. A number of 10-volt batteries are provided for the direct-current telegraph circuits over the cables. All batteries are charged from the local power mains through mercury arc rectifiers, with gas-engine-driven generators for charging in case the electric power supply fails. Battery circuits for supplying the terminal equipment pass through control apparatus mounted on the relay rack shown in Fig. 17. On the two sections at the left are rheostats for adjusting the filament currents of the vacuum tubes, with associated relays and resistances in these circuits, and also meters for measuring the filament and space currents and the voltages used. Another rack, not shown, carries the fuses and other protective equipment associated with the power supply.

Operation

The relation between the total transmission equivalent of the telephone channel over the cables, the available gains in the terminal amplifiers and the balance obtained between the cables and the balancing equipment was such that this channel could be operated at an efficiency materially higher than that required for connections terminating in Havana and Key West and also over a large range of current levels. As the cables were to be used in general as links in long circuits, the operating adjustments which were finally adopted were set rather by the circuits as a whole than by the cables. One of the cables was connected at Key West to a land line to form a direct New York-Havana circuit, a second cable to form a direct Jacksonville-Havana circuit and the third was arranged for a Key West-Havana circuit.

The New York-Havana circuit was set to have a transmission equivalent of 12 miles of standard cable. As the New York-Key West section has an equivalent of 10 miles, the net equivalent of the cable and terminal apparatus is only two miles. The Jacksonville-Havana circuit was set at 11 miles and the Key West-Havana at 10 miles. Switching through New York, operating equivalents are obtained for Havana-Chicago connections of approximately 16 miles and for Havana-San Francisco[17] of 20 miles. In addition to the submarine cables, the Havana-Chicago circuit contains 2453 miles (3940 km.) of land line and the Havana-San Francisco 4790 miles (7700 km.)

With these equivalents, satisfactory commercial connections can be established not only from Havana to points on the eastern part of the United States, but also to the Pacific coast. The application of repeaters to the Cuban toll lines makes it possible to establish commercial connections from points along the island to points in the United States. While the majority of the telephone connections over the cables have been for calls between New York and Havana, commercial calls have been handled satisfactorily to points all over the United States, such as Boston, Washington, Chicago, St. Louis, San Francisco, New Orleans and Atlanta, also to Toronto and Montreal in Canada, and to points in Cuba such as Matanzas, Sagua, and Santiago. The traffic between New York and Havana has been so large at times as to require two of the cables to be used in direct New York-Havana circuits.

The d-c. telegraph channels operate so well that their connection to land-line telegraph circuits from Key West to New York does not appreciably affect the maximum speed of the circuit. The carrier-current telegraph channels are good enough for the operation of four channel multiplex printers if it should be desired to use them for such service.

In planning this cable system it was intended that a demand for more telegraph facilities would be met by increasing the number of carrier channels per cable. As has been noted, the initial apparatus and land connections provided for the commercial operation of only six telegraph channels, one d-c. and one carrier channel per cable, on the basis that this number would meet the initial service requirements. In order, however, to obtain information regarding the operation of additional carrier channels and to provide spare telegraph facilities in case of cable failures, a fifth carrier telegraph set was provided at each terminal, together with special receiving selective circuits. With this apparatus three carrier telegraph channels were successfully operated over one cable, using frequencies up to 4200 cycles, for which the equivalent of the circuit between the terminal offices is 48 miles. It is possible that this number of channels can be further increased. The present arrangement of the carrier

17. The transcontinental line has been improved since the publication of the paper "Telephone Repeaters," Gehrardi and Jewett, Trans., A. I. E. E., 1919. The transmission equivalent of the New York-San Francisco circuit is now approximately twelve miles.

telegraph apparatus makes it possible, therefore, to carry six telegraph channels over two cables or four over one cable. This will prove very useful in maintaining service in case of cable failures.

At the time of the opening of service over these cables under the auspices of the Pan American Union, greetings were exchanged between the President and other officials of the United States at Washington and the President and officials of the Cuban government at Havana. In connection with this demonstration, the circuit was extended through New York and San Francisco to the Island of Santa Catalina, off the coast of California, in the Pacific Ocean. As this island is connected to the mainland by radio telephone[18], this connection, 5470 miles (8800 km.) in length, involves the radio connection through the air, a 5322-mile land line across the United States and the submarine cable from Key West to Havana. This circuit containing twenty-five telephone repeaters illustrates the possibilities of the present state of development of telephony.

The work described in this paper involved the application of ideas from practically all branches of the telephone and telegraph fields and from a number of organizations. The Western Electric Company was retained by the Cuban-American Telephone and Telegraph Company as engineers and purchasing agents for the cables and to manufacture and install the terminal apparatus. The Cuban Telephone Company retained as consulting engineer Sir William Slingo, who also assisted the Western Electric Company in the inspection of the cable during the manufacture and laying. The electrical design of the cables, the method of operation, the design and arrangement of the terminal apparatus and the adjustment of the system for operation were the work of the engineers of the American Telephone and Telegraph Company and the Western Electric Company. The Telegraph Construction and Maintenance Company, Limited, of London, which manufactured and laid the cables, was largely responsible for the mechanical features of the cables, such as the design of the armoring for the different depths of water involved and the arrangement of the copper tapes. The recommendations of the engineering firm Clark, Forde and Taylor, retained by the Western Electric Company, were obtained on many of these including the routes to be followed.

18. Clement, Ryan and Martin, "The Avalon-Los Angeles Radio Toll Circuit." *Proc. I. R. E.*, Dec. 1921.

ALINEMENT CHARTS

BY GEORGE L. HEDGES

Member, A. I. E. E.

An alinement chart provides the simplest and most convenient means of solving many engineering equations. It is simpler to use and usually much easier to construct than the ordinary curve graph. As an example the alinement chart herewith shows the efficiency-voltage relations of incandescent lamps from the equation

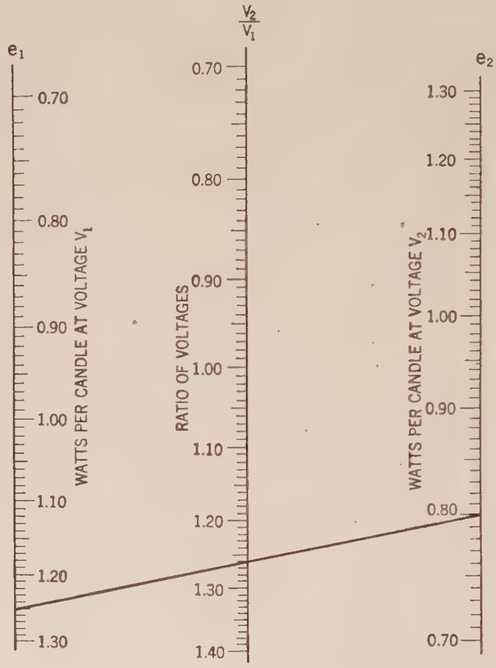
$$V_2/V_1 = \left(\frac{e_1 - 0.1700}{e_2 - 0.1700}\right)^{0.428}$$

(Eq. (2), Eisenmenger, "Simple Equations for the Lamp Performance," JOUR. A. I. E. E., Dec. 1921).

Not all equations can be plotted as alinement charts. But any equation can be so plotted which can be expressed so that each term of the equation is the function of a separate independent variable—that is in the form of

$$F(y) = F(z) + F(x) + \ldots$$

in which the individual quantities $F(y)$, $F(z)$, etc. must contain only the one variable y, x, etc. respectively. There will be one axis in the alinement chart



EFFICIENCY-VOLTAGE RELATIONS OF INCANDESCENT LAMPS

for each variable in the formula, the axes being graduated to the values of the functions of the variables and marked with the corresponding values of the variables.

The sample equation expressed for plotting as an alinement chart becomes

$$\text{Log } V_2/V_1 = [0.428 \log (e_1 - 0.1700)] - [0.428 \log (e_2 - 0.1700)]$$

As there are three variables the chart will have three axes. The outer axes are graduated with the values of $0.428 \log (e_1 - 0.1700)$ and $0.428 \log (e_2 - 0.1700)$ and are marked with the corresponding values of e_1 and e_2. The center axis is graduated with the values of log V_2/V_1 and marked with the corresponding values of V_2/V_1. (Note that the ratio V_2/V_1 is the variable for the center axis.)

Bibliography. "The Construction of Graphical Charts," Peddle, Rose Polytechnic Institute, gives the theory of alinement charts and of other graphical charts. "Alinement Charts," Hedges, Machinery, March, 1918 describes methods of construction of such charts.

Skin Effect and Proximity Effect in Tubular Conductors

BY HERBERT BRISTOL DWIGHT
Member, A. I. E. E.
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The effective a-c. resistance of tubular conductors is required to be predetermined by designers, for radio installations, for large underground cables with non-magnetic cores, and for electric furnace circuits. (See Examples I to IV).

For the above purpose, sets of curves are given in this paper. The skin effect ratio for isolated tubes is shown in Fig. 1. For stranded conductors, the resistance must be multiplied also by a ratio for the spirality effect, as is approximately indicated in Fig. 2. When the return conductor is near, a ratio for the proximity effect, as indicated in Fig. 3, is also to be used. A calculation for the proximity effect ratio for thin tubes is made, and the results are compared with tests in Fig. 3.

Some of the requirements for future research work on skin effect are discussed.

The conclusion is expressed that it seems scarcely worth while providing a non-magnetic core with a 2,000,000 cir. mil, 25-cycle cable in order to reduce the skin effect, but with the other cases considered, the tubular form seems very advantageous.

THE effective resistance of tubular conductors to alternating current is desirable to know in at least three classes of work in electrical engineering: Namely in radio work, where small currents are to be carried at high frequencies; in the design of large 60-cycle single-conductor underground cables with non-magnetic cores; and in the design of electric furnace circuits where currents of the order of 30,000 or 50,000 amperes at 25 and 60 cycles are to be carried. In all of these cases, tubular conductors of convenient shape may be designed, whose effective a-c. resistance will be not much greater than their d-c. resistance, while, if the tubular form were not adopted, the a-c. resistance would be from 30 to 200 per cent, or more, greater than the d-c. resistance. The large saving of copper by this device is obvious. However, the saving does not seem worth while for 2,000,000-cir. mil, 25-cycle cables.

In this paper, curves are given by which one can estimate the a-c. resistance of tubular conductors of various kinds. The skin effect ratio for isolated tubes is shown in Fig. 1. For stranded conductors, the resistance must be multiplied by an additional ratio for the spirality effect, as is approximately indicated in Fig. 2. When the return conductor is near, a ratio for the proximity effect as indicated in Fig. 3, is also to be used. A calculation for the proximity effect in thin tubes is given, and the results are compared with tests.

It is noteworthy that the curves and formulas given in this paper are not based directly on the frequency, size of conductor or specific resistance, but only on the ratio of f to R_{dc} where f is the frequency and R_{dc} is the d-c. resistance in ohms per 1000 feet of the complete conductor. Thus, skin effect ratios measured at 100,000 cycles are applicable to large 60-cycle conductors when their proportionate shape is the same, and the proportionate shape and position of the return conductors are the same. This principle was stated by the writer in a previous A. I. E. E. paper,[1] and a mathematical proof of it was given by J. Slepian in a discussion of the same paper[1] on page 1401.

The principle may be stated as follows: A conductor, or a combination of conductors, of a certain proportionate shape and a certain value of $\frac{f}{R_{dc}}$ will have a definite value of $\frac{R_{ac}}{R_{dc}}$. This is true of isolated conductors and single-phase and polyphase circuits.

If this principle of similitude is adopted by those making skin effect tests, they will plot their test results on a base of $\frac{f}{R_{dc}}$ or $\sqrt{\frac{f}{R_{dc}}}$ instead of on a base of f as has been usually done. If the principle is adopted by designers who require to know skin effect values, they will make use of tests made on any size of conductors and at any frequency, and will correct them mathematically according to the principle of similitude, having confidence that the results so obtained will apply to their particular case.

For the particular case of proximity effect in two tubular conductors forming a return circuit (See Fig. 3) the resistance ratio depends on the ratios $\frac{f}{R_{dc}}$, $\frac{t}{d}$ and $\frac{s}{d}$. When these ratios have been determined, the proximity effect ratio is fixed.

The principle is in agreement with the various calculated formulas for skin effect and proximity effect whether for wires, tubes or straps and whether isolated or in close proximity. In fact, the principle seems almost obvious to one calculating a skin effect formula, for the first step is often to calculate the voltage drop due to resistance and reactance at any point of the cross-section of the conductor. On equating

Presented at the 10th Midwinter Convention of the A. I. E. E., New York, N. Y., February 15-17, 1922.

1 "Skin Effect in Tubular and Flat Conductors," by H. B. Dwight, TRANS. A. I. E. E., 1918, page 1398.

this to a constant, one finds that the distribution of current over the cross-section of the conductor depends on the ratio f/R_{dc}. This is the basis of Mr. Slepian's general mathematical proof referred to above.

The writer has not seen any reliable test results of skin effect which tend to throw doubt on the above principle. In all tests published, the skin effect of

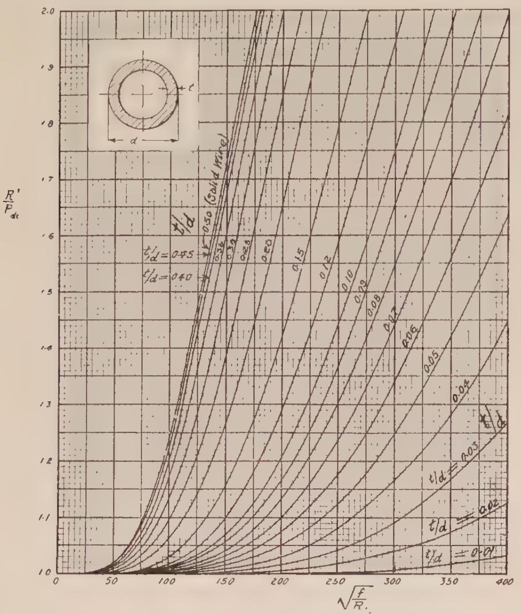

FIG. 1—SKIN EFFECT IN ISOLATED TUBES AND WIRES
R_{dc} in ohms per 1000 feet.

round, non-magnetic isolated wires has been found to agree with the standard Bessel function formula within the limits of the errors of observation. Most experimenters have first checked up the accuracy of their measuring apparatus by making this standard test, and this seems a logical and even necessary thing to do, for skin effect ratios are admittedly difficult to measure precisely. The measurements which, judged by this standard test, appear to be made the most accurately, show the closest agreement with the principle stated above. This applies also to the effect of the spirality of stranded conductors, which is, of course, only one feature of the shape of the conductors. It may be stated that the published tests made at 60 cycles do not show the same evidence of good accuracy as tests made at higher frequencies.

The curves of Fig. 1 show the skin effect in isolated tubes and wires. The skin effect in wires is well-known and a very complete and accurate table has been published by the Bureau of Standards.[2] The curves for skin effect in tubes are based on those published by the writer (see Dwight, loc. cit., Fig. 3). The curves for wires and tubes given in the present paper are plotted on $\sqrt{f/R_{dc}}$ which makes them much more useful for practical purposes. This method of plotting makes the curves independent of specific conductivity and temperature. The specific conductivity is difficult to measure precisely, as it depends on the small dimensions of the cross-section. On the other hand, the value of R_{dc}, the d-c. resistance per 1000 feet, is easy to measure precisely. The d-c. resistance of the conductor must be measured in every case in order to measure the ratio R'/R. The length of conductor whose resistance is taken is easily measured as it is several meters. This length and the d-c. resistance should always be stated when publishing skin effect tests. Thus, by plotting the curves on $\sqrt{f/R_{dc}}$, they are made of almost universal application, being applicable to copper or aluminum, high or low conductivity, high or low temperature, high or low frequency, large or small conductors and, except for spirality effect, solid or stranded conductors.

The curves are plotted on $\sqrt{f/R_{dc}}$ instead of f/R_{dc} because this makes the curves of Fig. 1 approach straight lines as asymptotes. This is indicated by the following formula, which is based on that derived by the writer, loc. cit., page 1403.

$$R'/R = \sqrt{f/R_{abs}}\sqrt{\frac{\pi\, t\,(q+r)}{r^2}}\left[1+\frac{1}{m\,r\sqrt{2}}\right.$$

$$\left.+\frac{3}{8\,m^2\,r^2}+\frac{0}{m^3\,r^3}+\ldots\right] \quad (1)$$

where $$m\,r = \sqrt{f/R_{abs}}\sqrt{\frac{8\,\pi\,r^2}{t\,(q+r)}} \quad (2)$$

where q is the inside radius of the tube, r is the outside radius and t is the thickness (See Dwight, loc. cit., page 1403) and where R_{abs} is the d-c. resistance of one cm.

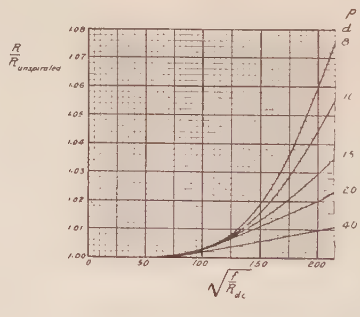

FIG. 2—SPIRALITY EFFECT RATIO IN SEVEN-WIRE CABLES
p = pitch of spirals.
d = diameter of cable.
R_{dc} in ohms per 1000 feet.

of the conductor in absohms. Note that $R_{abs} = 32{,}800 \times R_{dc}$ in ohms per 1000 feet. Equation (1) is applicable for large values of $\sqrt{f/R_{dc}}$ and it may be used to give approximate values of R'/R for parts of the curves beyond the range of Fig. 1. While Fig. 1 has been drawn up to cover as broad a range as possible, yet there are cases in which the value of t/d is extremely small, where it may be more convenient to use the curves of the writer's previous paper, loc. cit., Fig. 3.

2. Scientific Paper No. 169 of the Bureau of Standards, by E. B. Rosa and F. W. Grover, page 226.

Spirality Effect

As previously mentioned, the stranding of a conductor and the spiraling of the strands are features of the shape of the conductors. Therefore, a curve plotted on $\sqrt{f/R_{dc}}$ will show the effect of stranding and spiraling for a certain proportionate shape. Accurate tests have been published for seven-wire cables with both long and short pitch of spiraling[3] and the results are shown in Fig. 2. A test on a larger seven-wire cable made up to 5000 cycles[4] shows similar results. It is seen that even when the spiraling has a very short proportionate pitch, as in the case of the curve $p/d = 8$, only a small per cent is added to the a-c. resistance of an unspiraled or solid conductor of the same cross-section, for the range covered by the tests.

It has been shown by very accurate measurements (Kennelly and Affel, loc. cit., Fig. 10 and page 536) that the mere fact of dividing a conductor into parallel unspiraled strands touching one another does not increase the a-c. resistance appreciably. The increases shown in Fig. 2 are evidently due to the angle of spiraling and are

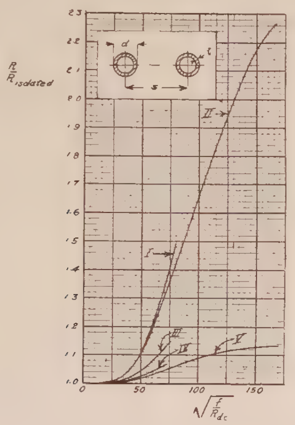

Fig. 3—Proximity Effect Ratio in Tubes

R_{dc} in ohms per 1000 feet.

I. $s/d = 1.0$, $t/d = 0$ (calculation).
II. $s/d = 1.008$, $t/d = 0.125$ (test).
III. $s/d = 1.5$, $t/d = 0$ (calculation).
IV. $s/d = 2.0$, $t/d = 0$ (calculation).
V. $s/d = 2.03$, $t/d = 0.125$ (test).

approximately inversely proportional to the pitch of the spiral. From the above it appears that Fig. 2 can be used to some extent at least for approximate results with cables of more than seven wires, and with stranded conductors with non-magnetic cores, that is, with stranded, tubular conductors.

The increase due to spirality is only a small fraction of the usual increase due to skin effect in a solid conductor, and it is, therefore, even more difficult to measure with precision. When tests at 500 cycles show a ratio due to skin effect plus spirality effect of 1.07 to 1.1 for a seven-wire cable of 0.0457 ohm per 1000 ft.,[5] and when it is known that this cable, if unspiraled, would have a calculated skin effect ratio of 1.284, the low test value can be ascribed only to an

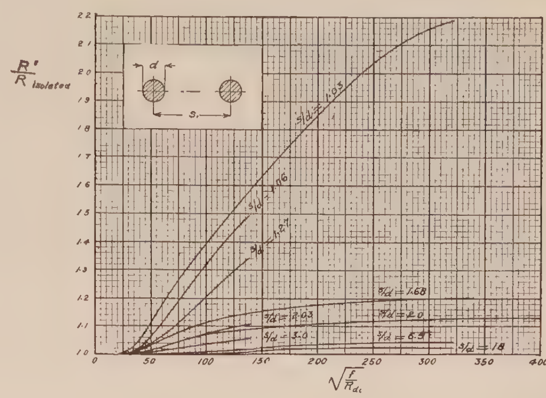

Fig. 4—Proximity Effect Ratio in Wires

R_{dc} in ohms per 1000 feet.

error in measurement. The possibility that there are errors in measurement in the low-frequency tests referred to is also indicated by the fact that measurements of the same a-c. resistance sometimes differ by as much as 8 per cent (See Table IX, Middleton and Davis, loc. cit., The conclusion stated by the authors that a seven-wire cable has much less skin effect than a cable of the same size in circular mils but with a larger number of smaller wires, and, in general, that copper cables with coarse strands have less skin effect than cables with fine strands, is quite untrustworthy. It is a generalization from a single test, and that test result is in direct contradiction to the proved accurate results of references 3 and 4.

Proximity Effect

When conductors are comparatively close together, there is an increase in their a-c. resistance caused by

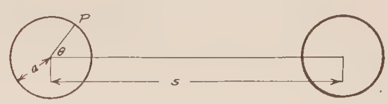

Fig. 5—Cross-Section of Return Circuit of Thin Tubes

the distortion of current due to their proximity. The proximity effect ratio may be defined as the ratio of the a-c. resistance when the conductors are near each other, to their a-c. resistance when they are isolated. So far as the writer is aware, only two or three tests have been published which show the proximity effect in tubular conductors. In the following paragraphs, mathematical formulas are developed for the proximity effect ratio of two extremely thin tubes forming a return circuit. The calculated results are plotted in Fig. 3, together with test results. The curves in Fig. 4, which are somewhat similar, show the proximity effect ratio in wires. From the above data, an approxi-

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3. A. E. Kennelly and H. A. Affel, *Proceedings* of the Institute of Radio Engineers, May, 1916. Fig. 17.

4. A. E. Kennelly, F. A. Laws and P. H. Pierce, Transactions A. I. E. E., 1915, page 1970, Table VI.

5. W. I. Middleton and E. W. Davis, Journal of the A. I. E. E., Sept., 1921, page 760, Table VII.

mate estimate can be made of the proximity effect ratio in tubular conductors in a given case.

As in the calculation of the formulas developed by the writer for skin effect in tubes and thin straps (Dwight, loc. cit., pages 1380 and 1392), a uniform current density over the section will first be assumed, and then successive increments of voltage drop and current will be calculated to agree with the actual condition that the voltage drop is uniform over the section.

The calculation applies to the case in which the ratio of the thickness of the tube to its diameter is very small. In such a case, the change in current density from the inner surface to the outer surface is inappreciable compared with the changes in current density in different parts of the tube, due to the proximity of the return conductor.

The reactive drop at the point P, Fig. 5, due to a uniform current density b_0 absamperes per sq. cm. in both tubes, is equal to

$$\omega\, 4\, \pi\, b_0\, a t \left[\operatorname{logh} \frac{s}{a} - \left\{ \frac{a}{s} \cos\theta + \frac{a^2}{2\, s^2} \cos 2\,\theta + \frac{a^3}{3\, s^3} \cos 3\,\theta + \ldots \right\} \right]$$

abvolts per cm. (3)

where $\omega = 2\,\pi\, f$ (4)

f = frequency in cycles per second (5)

and t = thickness of the tube. (6)

The reactive drop at P due to a current density $c_n \cos n\,\theta$ absamperes per sq. cm. in both tubes is

$$j\, l^2\, c_n\, \rho \left[\frac{\cos n\,\theta}{n} - \frac{a^n}{n\, s^n} \left\{ 1 + \frac{n}{\underline{/1}} \frac{a}{s} \cos\theta + \frac{n\,(n+1)}{\underline{/2}} \frac{a^2}{s^2} \cos 2\,\theta + \frac{n\,(n+1)\,(n+2)}{\underline{/3}} \frac{a^3}{s^3} \cos 3\,\theta + \ldots \right\} \right]$$

abvolts per cm. (7)

where n is not equal to zero, ρ is the specific resistivity of the conductor material in absohms per cm.³, (8)

and $$l^2 = \frac{\omega\, 2\,\pi\, a\, t}{\rho} = \frac{2\,\pi\, f}{R} \quad (9)$$

R being in absohms per cm. The angle θ is measured from the line joining the centers of the tubes.

Expressions (3) and (7) are derived in a manner similar to that used by H. L. Curtis[6] in calculating the proximity effect between wires for values of $\sqrt{f/R_{dc}}$ up to 140 (R_{dc} in ohms per 1000 ft.)

Assume that a current of uniform density, b_0 absamperes per sq. cm., flows in the tubes. The reactive drop at any angle θ is given by (3), and the total current is $2\,\pi\, a\, t\, b_0$ absamperes. Now assume a current of density b_1 whose resistance drop is equal and opposite to the terms in θ of (3). The reactive drop at any angle θ due to b_1 is obtained by applying equation (7) to the various terms in the expression for b_1. Numerical values of the coefficients for the Fourier series in $\cos\theta$, $\cos 2\,\theta$ etc., may be written down for a given value of s/a. Thus, when $s/d = 2$ $(d = 2\,a)$, the reactive drop at angle θ due to b_1 is

$$(j\, l^2)^2\, 2\, b_0\, \rho \left[-0.06350 + 0.23387 \cos\theta + 0.01152 \cos 2\,\theta + 0.00069 \cos 3\,\theta - 0.00002 \cos 4\,\theta - \ldots \right]$$

abvolts per cm. (10)

The term independent of θ in formula (10) is $(j\, l^2)^2\, 2\, b_0\, \rho\, (-0.06350)$ which is obtained from the series

$$(j\, l^2)^2\, 2\, b_0\, \rho \left[-\frac{a^2}{s^2} - \frac{a^4}{2^2\, s^4} - \frac{a^6}{3^2\, s^6} - \frac{a^8}{4^2\, s^8} - \ldots \right] \quad (10a)$$

This series is applicable for any value of s/a, and when $s/a = 4$ $(s/d = 2)$ it gives

$$+\, l^4\, 2\, b_0\, \rho \times 0.063504$$
$$= b_0\, \rho\, l^4 \times 0.12701$$

as in the second term of equation (13).

Since b_1 contains only terms in $\cos\theta$, $\cos 2\,\theta$, etc., the total current due to b_1 is zero, as is shown by the integral

$$\int_0^{2\pi} \cos n\,\theta\, d\,\theta = 0 \quad (11)$$

The process is continued by calculating the currents b_2, b_3 etc. The series for $I\,Z'$ will be composed of the terms independent of θ in the various expressions similar to (10).

Now $$I\,R = 2\,\pi\, a\, t\, b_0 \frac{\rho}{2\,\pi\, a\, t} = b_0\, \rho \quad (12)$$

By dividing this into the series for $I\,Z'$, we obtain the series for

$$\frac{R' + j\, X'}{R}.$$

The real terms give a series for R'/R.

Thus, when $s/d = 2$,

$$R'/R = 1 + 0.12701\, l^4 - 0.10965\, l^8 + 0.09599\, l^{12} - 0.08435\, l^{16} + 0.0742\, l^{20} - 0.0653\, l^{24} + \ldots \quad (13)$$

When $s/d = 1.5$

$$R'/R = 1 + 0.22872\, l^4 - 0.17337\, l^8 + 0.13619\, l^{12} - 0.10804\, l^{16} + 0.0860\, l^{20} - 0.0684\, l^{24} + \ldots \quad (14)$$

When $s/d = 1$

$$R'/R = 1 + 0.53530\, l^4 - 0.25686\, l^8 + 0.15408\, l^{12} - 0.0961\, l^{16} + 0.0604\, l^{20} - 0.0381\, l^{24} + \ldots \quad (15)$$

6. Scientific Paper No. 374 of the Bureau of Standards, Washington, D. C., 1920, by H. L. Curtis.

Now, from equation (**9**),

$$l = \sqrt{f/R}\,\sqrt{2}\,\pi \qquad (16)$$

when R is measured in absolute units. The principle that the value of skin effect depends on the value of f/R is self-evident for this type of circuit.

Equations (**13**) to (**15**) can be evaluated for values of l less than 1, that is, for values of $\sqrt{f/R_{dc}}$ less than about 72 (R_{dc} in ohms per 1000 ft.). Note that in this calculation the a-c. resistance when the tubes are isolated is the same as the d-c. resistance, since the tubes are assumed to be very thin.

Curves I, III and IV calculated as above for s/d = 1, 1.5 and 2 are plotted in Fig. 3 and are shown in comparison with test curves II and V, the data for which are given in Table VIII, of the paper by Kennelly, Laws and Pierce, loc. cit.

The curves for the proximity effect of wires (defined as R'/R_{isolated}) are not very different from those for tubes, when they are plotted on $\sqrt{f/R_{dc}}$. In Fig. 4 are plotted test curves described in Table V, Kennelly, Laws and Pierce, loc. cit., (s/d = 1.03, 1.68, 6.5 and 18), Table VI, Curtis, loc. cit., (s/d = 1.06, 1.27, 2.03 and 3.0) and a calculated curve for s/d = 2.0 published by J. R. Carson.[7]

These curves should be of some use in estimating the proximity effect in tubes, especially when the tubes are thick.

From the above it appears that there is opportunity for very useful measurements to be made of skin effect, spirality effect and proximity effect of tubular conductors as well as other types of conductors. The electrical engineering profession is much indebted to those who have made the tests so far published. These investigators have for the most part done their work so accurately that future tests, in order to add to our knowledge of the subject, must be made with very great precision and accuracy. Test results should not be presented as isolated results for certain sizes of conductor only, but they should be presented as general curves, applicable to all frequencies and all sizes of conductors or circuits of the specified shape. If there is any doubt in the minds of the investigators as to the propriety of doing this, they should remove such doubt by making a series of tests to check up the matter.

In this connection, it is necessary to point out that the "penetration formula" advocated by Middleton and Davis, loc. cit., is a formula which had been originally calculated and intended for very high frequencies, and it is inaccurate and liable to give rise to misleading results if used for large conductors at 60 cycles. This can be shown by plotting the results of the penetration formula alongside of the curve for solid wire in Fig. 1.

In deriving the penetration formula for solid wire, one starts with the high-frequency, asymptotic formula (**1**) of this paper, first making it applicable to solid wires by putting $t = r$ and $q = 0$. Next, discard all the terms of the series in the bracket except the first two, thus obtaining the equation of the straight line which is the asymptote to the curve of R'/R. This involves considerable error at low frequencies, where the curve of R'/R departs from a straight line, as is seen in Fig. 1. But there is another error, or approximation, still in the penetration formula. If R' is equal to the d-c. resistance of a tube of outer radius r and thickness t,

$$R/R' = \frac{2\,t}{r} - \frac{t^2}{r^2} \qquad (15)$$

In order to compare this with (**1**), the reciprocal of (**1**) is expanded by the binomial theorem, assuming that $m\,r$ is large, and the series is written

$$1 - \frac{1}{m\,r\,\sqrt{2}}\,.$$

The combined effect of the two approximations is found by plotting the results on Fig. 1. Besides giving actual errors for solid wires, the penetration formula as used by Middleton and Davis, loc. cit., (formula B), has the following disadvantages:

In using the constant 0.00384 for cables, it is assumed that the specific resistance of a mixture of copper and air such as the cable, is the same as the specific resistance of solid copper, but this is not the case. (This assumption is made also in Table II, Middleton and Davis, loc. cit.) By specifying the single constant 0.00384 for copper, no allowance is made for copper of low conductivity, or for changes in temperature, and these items are of considerable importance. By taking the penetration from the center line of the outside wires, an arbitrary assumption is made in order to make a few readings more consistent. The impression is given that the penetration formula can be used to determine the skin effect ratio of tubes, which is not at all correct.

The curves of Fig. 1 overcome the above disadvantages of the high-frequency penetration formula.

A 2,000,000-cir. mil cable, whose increase in resistance due to skin effect is of the order of 30 per cent at 60 cycles, is evidently worth while redesigning in order to reduce the skin effect. The increase in cost of manufacture and installation of the lead-covered cable due to the larger outside diameter when designed as a tube must be balanced against the decrease in cost due to less copper being required for the same a-c. resistance. In order to make such a comparison it is necessary to have a method of determining the skin effect in various designs of tubular conductors, and curves such as those of Fig. 1, together with curves to give a correction for spirality effect provide such a method. (See Example III.)

Care should be taken not to allow a cable carrying a heavy current to approach any magnetic material when precise measurements of the resistance loss are

7. "Wave Propagation over Parallel Wires: The Proximity Effect," by J. R. Carson, *Philosophical Magazine*, April, 1921, page 632.

being taken. If the cable is near a steel beam, or possbily even a number of nails in a wooden floor on which the cable might be lying, an appreciable increase in the effective resistance could be caused.

It is to be hoped that further precise tests of skin effect will be made, so that the curves required in designing can be made more accurate and more complete.

Example I

Find the a-c. resistance at 60 cycles of a non-flexible lead for a 15,000-ampere resistance furnace. With certain types of furnace which have a long, narrow shape, it is necessary to construct such a lead 40 or 50 feet long parallel to the furnace and about 6 feet away from it. The furnace is itself the return conductor, so that interlacing is impossible.

First assume a round, solid conductor with average current density 1000 amperes per sq. in., that is, with 15 sq. in. cross-section.

R_{dc} = 0.00072 ohm per 1000 feet at 100 deg. cent.

$\sqrt{f/R_{dc}} = 288$ and $\sqrt{f/R_{abs}} = 1.59$

$R'/R = 1.59\sqrt{\pi} + 0.25 = 3.07$ by formula (1).

The proximity effect ratio is 1.03, since $s/d = 16$ (See Fig. 4).

Therefore, the a-c. resistance of the solid, round conductor is 0.0023 ohm per 1000 feet. The a-c. resistance of a bundle of cables is practically the same as that of the solid conductor. The a-c. resistance of any non-tubular form of conductor, such as a group of ventilated straps, is very much greater than the d-c. resistance and so it is worth while considering a tubular conductor, as in the following paragraph.

Assume that the conductor is a tube of 12 inches diameter, made of copper sheet 0.35 inch thick.

Section = 12.8 sq. in.

R_{dc} = 0.00084 ohm per 1000 feet at 100 deg. cent.

$t/d = 0.029$

$\sqrt{f/R_{dc}} = 267$

Therefore, $R'/R = 1.05$ from Fig. 1.

Since $s/d = 6$, the proximity effect ratio will be of the order of 1.1. (See Fig. 3).

The a-c. resistance of the tube at 60 cycles is thus about 0.0010 ohm per 1000 feet. The tubular conductor is seen to have double the a-c. conductivity of the non-tubular form, although the weight is 15 per cent less. The weight could evidently be reduced still further.

The large diameter of the tubular lead reduces the reactance and raises the power factor of the 60-cycle furnace load, which is sometimes desirable. If the heated air and the radiation from the furnace cause the lead to run too hot, the tubular shape is advantageous in that cool air from outdoors can be blown through it by a ventilating fan.

Example II

To estimate the a-c. resistance of a flexible electric furnace lead for 30,000 amperes.

First, if the lead is composed of a bundle of bare cables tied closely together, with the average current density in the copper equal to 1000 amperes per sq. in., the value of R_{dc} for the lead will be 0.00036 ohm per 1000 feet at 100 deg. cent. This depends directly on the fact that the cross-section of the copper is 30 sq. in. At 60 cycles

$\sqrt{f/R_{dc}} = 408$ and $\sqrt{f/R_{abs}} = 2.25$

$R'/R = 2.25\sqrt{\pi} + 0.25 = 4.25$ from formula (1).

The spirality effect ratio will be comparatively small, being of the order of 1.2. The proximity effect ratio for a three-phase circuit will not be greatly different from that for a return circuit indicated in Fig. 4. This ratio will also be small, being of the order of 1.03 if the leads are 6 feet apart, s/d being about 10.

The a-c. resistance of the lead is therefore approximately 0.0019 ohm per 1000 feet.

Second, if the lead is designed as a hollow, flexible cylinder composed of 70 cables of 400,000 cir. mils each, held apart by 20-inch circular spacers, the total section of copper is 22 sq. in. Therefore, $R_{dc} = 0.00050$ and $\sqrt{f/R_{dc}} = 346$ at 60 cycles and 100 deg. cent.

The cylinder made up of a single layer of cables is quite similar to a tube of thickness 0.72 inch or less so that $t/d = 0.034$. Therefore, from Fig. 1, $R'/R = 1.20$. The proximity effect ratio is about 1.2, as may be seen from Fig. 3, taking $s/d = 3.4$ The spirality effect ratio is of the order of 1.2 as for the more compact bundle of cables previously considered.

The a-c. resistance of the flexible tubular lead is, therefore, approximately 0.00086 ohm per 1000 feet.

It is seen therefore that the tubular lead, which has 25 per cent less weight than the non-tubular form, has over twice as much a-c. conductivity. Since the tubular lead is very well ventilated, its weight could doubtless be cut down considerably. The exact dimensions used above are for an example only to show the method of estimating the a-c. resistance.

The writer understands that this tubular form of flexible lead has been constructed and successfully used with electric furnaces and that it is sufficiently flexible for the purpose. A little calculation will show that its reactance is enough less to increase the power factor of the furnace load appreciably. An easy method such as the one here given of estimating the greatly increased conductivity of tubular leads compared with more usual designs should help make them be applied more frequently.

Example III

To find the a-c. resistance at 60 cycles of a 2,000,000 cir. mil cable both without and with a non-conducting core.

R_{dc} = 0.0054 ohm per 1000 feet.

$\sqrt{f/R_{dc}} = 106$

$R'/R = 1.29$ for the coreless cable, from Fig. 1.

Therefore the a-c. resistance is 0.0069 ohm per 1000 feet, neglecting spirality effect.

If a 2,000,000-cir. mil tubular cable be wound on a non-conducting core 1.125 inches in diameter, the outside diameter, d, of the copper will be approximately 1.96 inches.

Therefore, $t = 0.417$ inch and $t/d = 0.213$

As above, $\sqrt{f/R_{dc}} = 106$

and therefore, from Fig. 1, $R'/R = 1.08$. Thus the a-c. resistance is 0.0058 ohm per 1000 feet, neglecting spirality effect.

The spirality effect ratio would be small for both the above cases since $\sqrt{f/R_{dc}} = 106$ (See Fig. 2).

Example IV

To find the a-c. resistance at 25 cycles of a 2,000,000-cir. mil cable both without and with a non-conducting core.

$R_{dc} = 0.0054$ ohm per 1000 feet.

$\sqrt{f/R_{dc}} = 68$

$R'/R = 1.063$ for the coreless cable, from Fig. 1.

Diameter of copper = 1.67 inches. Assume that a return conductor is at a distance of 8 inches, center to center. Then $s/d = 4.8$ and the proximity effect ratio is about 1.010 (See Fig. 4). The spirality effect at 25 cycles is practically negligible (See Fig. 2).

Second, assume that a non-magnetic core of 0.625 inch diameter be provided, as recommended in Table XV, Middleton and Davis, loc. cit., for a 2,000,000-cir. mil cable at 25 cycles. The diameter of the copper is increased to 1.78 inches and from this

$$t/d = 0.324$$

Now $\sqrt{f/R_{dc}} = 68$ and therefore,

$$R'/R = 1.035 \text{ from Fig. 1.}$$

As before, the spirality effect is practically negligible. The proximity effect ratio, as given by Fig. 3, is about 1.015. The slight increase in proximity effect is due to two reasons. First, the value of s/d has been decreased to 4.5 and, second, a comparison of Figs. 3 and 4 shows that the curves for tubes are slightly higher than those for wire, as would be expected from the nature of the problem.

Providing a non-magnetic core as above has therefore decreased the a-c. resistance 2.8 per cent as regards Fig. 1, increased the a-c. resistance 0.5 per cent as regards Figs. 3 and 4, and increased the diameter of the copper 6.6 per cent, thus increasing the surface for heat radiation slightly.

From these results, it does not seem to be worth while to put a non-magnetic core in a 2,000,000-cir. mil, 25-cycle cable in order to reduce the skin effect, and still less worth while in a 1,500,000-cir. mil, 25-cycle cable as recommended in Table XV, Middleton and Davis, loc. cit. The skin effect ratio of the latter cable, without a core is 1.03.

HARNESSING THE RIVER RHONE

Detailed information regarding the harnessing of the River Rhone for power, navigation, and irrigation is contained in a report just received by the Department of Commerce from Commercial Attaché W. C. Huntington, at Paris.

An outline of France's wealth in waterpower is given, with particular reference to the River Rhone as the most important source of potential hydroelectric power in France. The report also includes a history of the utilization of the Rhone and an explanation of a new law applying to the power development of this river. Estimates place the total cost of the proposed developments at 1,848,000,000 francs. The financing of this project will be accomplished by a gradual carrying out of the entire scheme, extending over a period of years.

Practical steps have already been taken toward the establishment of a great national Rhone development company, and there is little doubt that force of circumstances will compel the development, in one form or another, of this national resource.

Copies of the above report and of the law authorizing the power development of the River Rhone, together with an outline of the progressive financing scheme for the project, may be obtained from the Electrical Equipment Division of the Bureau of Foreign and Domestic Commerce or from the Bureau's district offices.

RESISTANCE OF BATTERY SEPARATOR PLATES

Measurements of separator resistances on a number of samples of different kinds of wood, made by the Bureau of Standards, have been completed. A comparison of these results with ones obtained on similar samples last May shows excellent agreement and prove that the method for measuring the resistance is reliable. The soft woods, such as popar and basswood, have the lowest resistance, cedar and cypress, on the other hand, have considerably higher resistance but are known to have better lasting qualities when used in storage batteries.

In determining the endurance of the separators in sulphuric acid solutions of different densities, a number of samples have been cut to a specified size and immersed in an acid solution of known concentration. One set is being kept at room temperature and a similar set at 45 deg. cent. At the end of periods of 1 month, 3 months, and 6 months, samples will be withdrawn to determine the decrease in tensile strength.

It has been definitely shown that very accurate control of the temperature of molten metal is necessary in the determination of gases evolved in vacuo. The higher the metal is heated above its melting point the greater the quantity of gas evolved in a given time.

Condenser Discharges Through a General Gas Circuit

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Review of the Subject.—*Any change in the electrical conditions of a circuit, whether internal, such as a change of load, starting and switching operations, short circuits, or external, such as due to lightning, involves a readjustment of the stored electromagnetic and electrostatic energy of the circuit, that is a so-called transient. Such transient is of the general character of a condenser discharge through an inductive circuit. The phenomenon of the condenser discharge through an inductive circuit therefore is of the greatest importance to the engineer, as the foremost cause of high-voltage and high-frequency troubles in electric circuits.*

With the development of radio communication—whether wireless or wired—the condenser discharge through an inductive circuit has assumed a great additional importance since, with the exception of a few of the highest power transoceanic stations, which use power-driven high-frequency alternators, the source of power in all radio communication is the condenser discharge through the inductive circuit, whether as a damped wave or as an undamped wave. In undamped wave radio communication, the condenser discharge circuit is coupled with a source of electric power—a battery—in such a manner, that, without interfering with the character of the oscillation, sufficient energy is fed into the circuit to maintain the oscillation, similarly as in the clock, the pendulum is coupled with a source of mechanical power—weight or spring—so as to maintain its oscillation undamped.

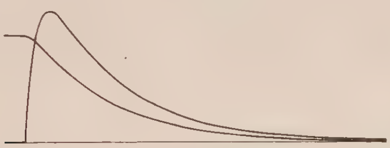


FIG. A

The condenser discharge through an inductive circuit is thus one of the most important phenomena with which the electrical engineer has to deal.

The classical equations of the condenser discharge through an inductive circuit were given a very long time ago, and are contained in all text books.

According to them, if the ohmic resistance r of the circuit is greater than a certain critical value $r_0 = 2\sqrt{\frac{L}{C}}$, *the discharge is unidirectional and non-oscillatory, that is, the voltage and current gradually die out without ever reversing in direction, and vanish, theoretically, after an infinite time, as illustrated in Fig. a for the case* $r = 1.5\, r_0$.

If the ohmic resistance r is less than the critical value r_0, *the discharge is oscillatory, that is, voltage and current perform a series of oscillations of gradually decreasing amplitude, but constant frequency, each half wave being less than the preceding one by a constant percentage, until finally, after a theoretically infinite number of half waves, the current and voltage become zero, as illustrated in Figs. b and c. Fig. b shows a rapid damping, due to the resistance of the circuit being not much less than the critical resistance,* $r = 0.5\, r_0$; *and Fig. c shows the slow damping that is, the more sustained oscillation, appearing in a low-resistance circuit,* $r = 0.1\, r_0$. *The half waves of current and of voltage are not sine waves, but are the product of a sine wave and an exponential, due to damping effect of the resistance, therefore the first part of each half wave is greater than the last part, and the maximum is not in the middle, but before the middle, as is best seen in Fig. b.*

These classical equations of the condenser discharge however apply only when the resistance of the circuit is constant, or practically so, that is, when all the energy dissipation occurs in a metallic or electrolytic resistance; that is, a resistance consuming a voltage proportional to the current, and in which therefore the voltage drop in the resistance becomes zero for zero current. These classical equations however do not apply even approximately, when the resistance of the circuit is not constant but varies with the current, as is the case in a gas circuit, such as a spark gap, vacuum tube, etc., as has been pointed out before. It is rarely that the condenser discharge through an inductive circuit does not include, at least, as a part of its energy-dissipating resistance, a gas circuit.

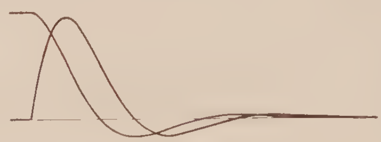


FIG. B

The usual method of producing a condenser discharge through an inductive circuit is gradually to charge a condenser from a source of electric power, until the condenser voltage has risen sufficiently high to jump a spark gap (the rotary gap, or quenched gap of the damped wave wireless for instance) and thereby discharge through the inductive circuit. In lightning disturbances of electric systems, and in high-voltage high-frequency disturbances, due to internal causes, an arc or spark discharge almost always is in circuit. The discharge of the lightning arrester which protects electric circuits, generally, occurs over a spdrk gap. In the production of undamped waves for radio communication, a vacuum tube is in circuit. The path of the lightning discharge in the clouds, or between clouds and ground, is entirely within the air, and the voltages and currents induced in transmission lines by the lightning flash naturally follow the voltage and current wave shape of the lightning flash, which is not that of the classical equations. A condenser discharge containing no gas path, like that of the bound charge of an overhead ground wire, set free by a cloud discharge, is rare

FIG. C

Obviously the larger the part of the total energy dissipation of the condenser discharge which occurs in a gas path, the more the discharge equations differ from the classical equations, so that, while the latter may give a fair approximation when the gas path constitutes only a small part of the energy dissipation, when it represents all or a large part of it, the classical equations become unsatisfactory. In view of the high industrial importance of the condenser discharge through an inductive circuit, and the relatively small amount of work done on the general equations of a condenser discharge through a non-ohmic resistance, a further study of it appears appropriate.

Presented at the 10th Midwinter Convention of the A. I. E. E., New York, N. Y., February 15-17, 1922.

When dealing with a non-ohmic resistance, that is, a resistance varying with the current, it usually is preferable to drop the term "resistance", and deal with the relation between the current i and the voltage E. Thus, the general differential equations of the problem are derived from the classical equations by adding a term E, which is the potential drop across the gas path, or, in general the non-ohmic resistance. This voltage E is a function of the current i, and often also of the time t—where there is a lag of the effective resistance, that is an asymmetry between rising and decreasing current. As i also is a function of the time, E is a function of the time, and can be expressed by a Fourier series (multiplied by an exponential). This gives a general differential equation, which is integrated by the product of exponential function and Fourier series, and the constants of the integral equation—the integration constants and the indeterminate coefficients of the Fourier series—then follow from the terminal conditions, that is, the values of current and condenser voltage at time zero, and the relation between E and i in the gas path, that is, the volt ampere characteristic of the gas path, as shown in the mathematical part of the paper.

The general characteristics of the current flow through a gas circuit—arc, spark, vacuum tube, etc.,—is that the effective resistance" is not constant, but varies with the current, decreases with increases of current and becomes infinite for zero current. Or, considering the relation between current and potential drop, that is, the volt-ampere characteristics of the gas path—as more satisfactory in such circuits—the current is not proportional to the voltage, but no current (except a negligible ionic current) flow until a finite voltage E_1—the ionization voltage or disruptive voltage of the gas path—is reached. Then the current begins, and with increase of current, the potential drop across the gas path either remains approximately constant (as shown in oscillograms 1 and 2, low vacuum tube), that is, the effective resistance decreases inverse proportional to the current, or the potential drop decreases with increase of current (as shown in oscillograms 3, high vacuum tube), that is, the effective resistance decreases more than inversely proportional to the current. With decrease of current, the potential drop then increases again, to the final value E_2 at zero current (E_2 usually being smaller than E_1). At the reversal of the current, the potential drop across the gas circuit thus suddenly changes, from E_2 to $-E_1$, that is, shows a discontinuous or abrupt change by $E_1 + E_2$, as shown by the oscillograms.

There can be no instantaneous voltage change at the condenser, since such would mean an instantaneous change of condenser charge, and thus an infinite current. The change of potential drop across the gas path, at zero current, thus must be neutralized by an equal but opposite instantaneous change of the inductance voltage, and as the inductance voltage is proportional to the rate of change of the current, the rate of change of current, that is, the slope of the current wave, must abruptly change at the current reversal. Wherever therefore a gas path is in circuit the slope of the current wave abruptly changes at zero current, as shown in the oscillograms and frequently observed before, though its meaning has not always been realized. The voltage and current waves however must remain continuous.

As it is not possible to integrate over a discontinuity, the integral equations of the condenser discharge through a circuit containing a gas path can apply only for one half wave of current. It therefore is not possible to get a set of equations to represent the complete discharge, but for every half wave of current of the discharge, a new set of equations applies, as shown in the numerical examples. In general the equations of discharge current and voltage are of the same form throughout, but have different cons ants for every half wave. The constants for the first half wave are derived from the initial terminal conditions, that is, the values of current and condenser voltage at the beginning of the discharge. The constants of the second half wave are derived from the final values at the end of the first half wave as initial values of the second half wave, and so on.

As the frequency is one of the constants derived from the terminal conditions, the different terminal conditions of the successive half waves may give different values of frequency for the different half waves of the same discharge. This is the case, and the frequency that is, the durat on of the successive half waves is not the same, but the frequency decreases. In other words, the duration of the successive half waves, or the wave length, increases, especially towards the end of the discharge, as is quite noticeable in the oscillograms. This increase of wave length may be quite considerable, as much as 25 to 30 per cent for the last half wave in some of the instances given in the paper. This feature may have some bearing in damped radio telegraphy, by limiting the sharpness of the possible tuning.

With a gas path in the circuit requiring a finite voltage E_1 for the current to start, it follows that if the initial condenser voltage e_0 is greater than E_1, the discharge takes place; if e_0 is less than E_1 no discharge occurs. The classical condenser discharge equations always give a discharge, whatever may be the value of the condenser voltage e_0.

From this it also follows that the condenser discharge through a gas circuit can have only a finite number of half waves, and not an infinite number of progressively increasing values, as given by the classical equations. At every successive half wave of discharge, the condenser voltage e is less than that of the preceding half wave, due to the energy dissipation in the circuit, and therefore, at a finite number of half waves, the condenser voltage e must drop below the voltage E_1, required to initiate the current through the gas path, and then the discharge abruptly stops leaving a finite voltage e, and therefore charge, in the condenser. This may be in the same or in opposite direction to the initial charge e_0, as seen on the oscillograms and the numerical examples calculated in the paper. Thus the condenser discharge through a gas circuit consists of a finite number of half waves, after which it abruptly stops, and it does not completely discharge the condenser, but leaves a "residual" voltage and charge on the condenser. The number of half waves is less the greater the energy dissipation and the more rapid therefore the decrease of the condenser voltage, so that at high energy dissipation, only a single half wave of current may occur, as shown in some of the examples. In this case, the discharge is unidirectional, but differs from the non-oscillatory discharge of the classical equations in that the current abruptly goes down to zero and a voltage is left on the condenser, while in the classical equations the current and voltage gradually fade out.

The simplest case is a condenser discharge through an inductive circuit of negligible ohmic resistance, but containing a gas circuit in which the counter e. m. f. is constant. The gas path then acts as a constant counter e. m. f. If the initial condenser voltage is e_0, the discharge current is that of the resultant voltage $(e_0 - E)$ through an inductive circuit of negligible resistance, and is thus a sine wave. At the end of the first half wave the resultant voltage has reversed, being $-(e_0 - E)$, and with E as the counter e. m. f. of the gas path, this leaves $-(e_0 - E) + E$, or $-(e_0 - 2E)$ at the condenser. The second half wave of discharge is again a sine wave, but starting with the condenser voltage $-(e_0 - 2E)$, lower by $2E$, than the condenser voltage with which the first half wave started. Thus the resultant voltage is $-(e_0 - 2E) - E = -(e_0 - 3E)$, since during the second half wave $-E$ is the counter e. m. f. of the gas path. In this case, there is not attenuation or decay during the half wave, but the half waves are sine waves, and all the decay due to the energy dissipation in the gas path occurs discontinuously at the current reversal by the successive half waves of current and voltage being lower by a constant value.—the value due to $2E$, the voltage discontinuity at the current reversal.

It is interesting to note therefore, that no matter how high the energy dissipation in the gas path, that is, the effective resistance of the gas circuit, it has no effect whatever on making the discharge non-oscillatory, but the discharge through a gas path is always oscillatory, no matter how high the energy dissipation, Thus the lightning flash must always be oscillatory, though, if the energy dissipation is very rapid—as in the faint terminal streamers of a branch discharge— the oscillation may consist of one half wave only, as in Figs. 2(I) and 3(I) of the paper.

Such a condenser discharge through a gas circuit having a constant counter e. m. f., E, thus becomes non-oscillatory only, if in addition to the gas path, there is an ohmic resistance r in circuit greater than the critical resistance r_0 of the classical equations. Discharge waves of this character are given in Fig. 1 (*III*) *of the paper for the case of negligible ohmic resistance, and in Fig.* 1 (*II*) *if the discharge circuit contains ohmic resistance besides the gas path.*

Consider a gas circuit like that in oscillogram 3, in which the potential drop across the gas circuit decreases with increase of current, and therefore is a maximum E_1 at zero current, and a minimum E_m at high current. Then at the beginning of each half wave, the current starts at the rate of a sine wave discharge of the condenser voltage e_0 with a counter e. m. f. E_1, but with increasing current, the counter e. m. f. decreases, the more the greater the difference between E_m and E_1, and the resultant voltage $(e - E)$ thereby increases. That is the current increases at a greater rate than it would in a sine wave—the reverse of that in the classical equations— so that the first part of the current half wave is lower than the last part, and the current maximum is beyond the middle of the half wave, as shown in the oscillograms and numerical examples. That is, each half wave has the character of a cumulative oscillation, and the exponent of the exponential term is positive. (Such discharge waves are impossible with the classical equations.) Therefore, in the case of a gas path with double peaked potential drop, an attenuation occurs at the current reversal lowering the height of the following half wave below that of the preceding half wave; but in the following half wave a cumulative effect occurs and again increases the height of the half wave, Necessarily, the cumulative effect, being due to the difference $E_1 - E_m$, is less than the attenuation, which is due to E_1, so that the result is a decay of the discharge as obvious, but at a rate less than corresponds to E_1.

Or, in other words, at the current reversal, an attenuation or wave decay occurs, greater than that corresponding to the energy dissipation in the circuit, and during the following half wave, a cumulative effect occurs, returning the energy and reducing the attenuation to that corresponding to the energy dissipation. The effect is then of the character of a discharge through a circuit having a constant counter e. m. f., E_1, and a negative resistance. It is interesting to note, that in such a circuit an ohmic resistance r can be inserted, equal and even greater than the critical resistance r_0 of the classical equations, and the discharge nevertheless remains oscillatory. It becomes non-oscillatory only when the ohmic resistance, inserted in series to the gas path, is greater than the sum of the critical resistance r_0 and the apparent negative resistance of the gas path.

Numerical examples of such a discharge are given in Figs. 2 (*III*) *and* 3 (*III*) *of the paper, for the case of negligible ohmic resistance, and in Figs.* 2(*I*) *and* (*II*) *for the case of the circuit containing ohmic, that is, constant, resistance in addition to the gas path.*

The maximum value, which the negative resistance of the gas path can reach is equal to the critical resistance r_0.

The general method of integration described in the foregoing, applies not only to symmetrical circuits, that is, gas circuits in which the potential drop for rising current is the same as for decreasing current, but also for unsymmetrical gas circuits, or circuits in which the potential drop at decreasing current is different, almost always less, than for increasing current. Examples of both types of discharge are given in the paper, Figs. 1 *and* 2 *being symmetrical, and Figs.* 3 *and* 4 *unsymmetrical discharges. As the integration takes place step by step for each half wave, the method applies equally to so-called unidirectional gas circuits, that is, gas circuits having a potential drop which for current flow in one direction is different, often very many times greater, than for current flow in the opposite direction, such as the circuit of a vacuum tube with one incandescent and one cold electrode, etc., such as so-called rectifing circuits. Examples of such are given in Fig. 7.*

To conclude then; the condenser discharge through an inductive circuit of negligible ohmic resistance, but containing a gas circuit, if always oscillatory.

The oscillation consists of a finite number of half waves, the less, the greater the energy dissipation in the gas path.

The oscillation stops abruptly, leaving a finite voltage and charge in the condenser, which may be in the same or in the opposite direction to the initial voltage.

The frequency of the successive half waves is not constant, but decreases, that is, the wave length decreases, in the successive half waves. If the potential drop across the gas circuit is constant the discharge consists of pure sine half waves. In a circuit of negligible ohmic resistance, the successive half waves decrease by a constant difference.

In such a circuit, the discharge becomes non-oscillatory only if in addition to the gas path, it contains an ohmic resistance greater than the critical resistance of the classical equations.

If the potential drop across the gas circuit decreases with increasing current, the discharge waves are cumulative, that is, the current increases during each half wave, and the decay of the wave is produced by the amplitude of the successive half waves decreasing at the current reversal, but the exponent of the exponential term is positive.

Such a circuit acts like a combination of a constant counter e. m. f. and a negative resistance.

The discharge through such a circuit becomes non-oscillatory only if, in addition to the gas circuit, it contains an ohmic resistance greater then the sum of the critical resistance of the classical equations plus the negative resistance of the gas circuit.

The condenser discharge through an inductive circuit containing in addition to an ohmic resistance a gas path, is intermediate between the discharge through a pure gas path and the classical condenser discharge equations, but always retains the characteristics of the discharge through a gas path, of a finite number of half waves, a residual charge on the condenser, a decrease of the frequency and a change and often reversal of the attenuation constant.

THE usual equations of the condenser discharge through an inductive circuit, as given in the textbooks, give an oscillation of progressively decreasing amplitude, if the circuit resistance is less, and an impulse or unidirectional discharge, if the circuit resistance is more than twice the surge impedance. They apply only for the case in which the resistance of the circuit is constant, that is, independent of the current, and therefore do not apply to the very common case in which the discharge circuit includes a spark gap or largely consists of a gas path (as is the case with the lightning flash). Experience shows that the phenomenon is essentially different; for instance, the condenser does not completely discharge, but a residual charge remains, which may be in the same, or in opposite direction to the initial charge.

A study of these more general discharge equations thus is of interest, and is given in the following in a somewhat different form from previous publications.

Let an electric circuit contain a constant capacity C, a constant inductance L, a constant ohmic resistance r, and an effective resistance r', the voltage E of which varies with the current in any desired manner:

$$E = i\,r' = f(i)$$

such as that of an arc, spark or vacuum discharge (lightning).

Characteristic of such gas or vacuum discharges is, that the voltage E does not vanish for zero current, but reaches a finite value at $i = O$, that is, the "effective resistance" r' becomes infinite at zero current. Usually, the voltage E is a maximum for zero current, and decreases with increasing current.[1]

Some approximate empirical equations which have been proposed for such discharges, are:

Gas discharge $E = r' i = \dfrac{a}{1 + b i}$;

where a = disruptive strength of residual ionization of discharge path.

Arc $E = r' i = e_0 + \dfrac{a (l + \delta)}{\sqrt{i}}$

where e_0 = terminal drop, l = length of arc, and δ = terminal effect on arc stream.

Geissler Tube $E = r' i =$ const. (approximation, at fairly high gas pressures especially)

In all these cases, where the voltage E does not disappear, but reaches a finite value E_0 at zero current, it must as counter e. m. f. of energy dissipation in the discharge path, abruptly change at the current reversal, from $+ E_1$ to $- E_0$, that is, the counter e. m. f. E contains a discontinuity at $i = O$.

In a circuit containing inductance and capacity, neither current nor voltage can change abruptly, that is, instantly, but both must be continuous, since a discontinuity of current would give an infinite e. m. f. of self-induction, a discontinuity of voltage an infinite capacity current. Thus the discontinuity of the counter e. m. f. of the discharge path must be compensated by an equal and opposite discontinuity of the counter e. m. f. of self-induction, that is by a discontinuity in the slope of the current wave.[2]

Due to the discontinuity of the slope of the current wave at the current reversal, the integration cannot be carried over the current reversal, but a different set of integral equations applies to each half wave of current. The integral equations of the successive half waves usually have the same form, but differ from each other by their integration constants derived from the terminal conditions: The initial terminal conditions of each half wave being the final terminal conditions of the preceding half wave.

1. In some conductors, with increasing current, the voltage E reaches a minimum, and then increases again with further increase of current. (pyro-electric conductors.)

2. Such discontinuities of the slope of the current wave are shown by the oscillograph in circuits containing such conductors, as those of rectifiers, circuit breakers, etc. For some such oscillograms, see "Transient Phenomena," II Section, in the chapter on arc rectification. Also see the following oscillograms, Figs. 8 to 10.

General Case

The differential equations of the discharge of a condenser of constant capacity C and initial voltage e_0, through a constant inductance L, a constant resistance r, and a circuit of counter e. m. f. $E = f(i)$, (lightning flash, Leyden jar discharge), are then given by:

Voltage at condenser terminals

$$e = L \frac{d i}{d t} + r i + E$$

(1)

Current in discharge circuit

$$i = C \frac{d e}{d t} \qquad (2)$$

with the terminal conditions

$$t = 0 ; \qquad i = 0 ; \qquad e = e_0 \qquad (3)$$

Differentiating (1) and substituting (2), therein, gives

$$L \frac{d^2 i}{d t^2} + r \frac{d i}{d t} + i/C + \frac{d E}{d t} = 0 \qquad (4)$$

As i is a function of t, $E = f(i)$ may be expressed as a function of time

$$E = f(i) = f'(t)$$

and in the interval between two successive zero values of i, $f(i)$ can thus be expressed by a Fourier series of t.

Instead of expressing $f(i)$, without loss of generality, the function

$$F(t) = \epsilon^{ct} (B_0 - f(i)) \qquad (5)$$

can be expressed in a Fourier series, where c is still an arbitrary constant, and B_0 chosen so that $f(i)$ has no constant term.

This gives

$$E = f(i) = B_0 - \epsilon^{-ct} F(t)$$
$$= B_0 - \epsilon^{-ct} \Sigma \{B_k \sin k q t + B_k' \cos k q t\} \qquad (6)$$

where c is an exponential decrement, and q the wave length constant, that is, $q t = \pi$ gives the interval between two successive zero values of current. c and q appear as integration constants.

[Equation (5) excludes the case of the impulsive discharge, in which the current reaches zero only after infinite time, as occurs for $f(i) = 0; r \geqq 2 \sqrt{L/C}$. This case is of no importance here.]

In view of equation (6), (4) is integrated by

$$i = \epsilon^{-ct} \Sigma \{ A_k \sin k q t + A_k' \cos k q t \} \qquad (7)$$

As the integration is carried over one half wave only, we can, without loss of generality, assume the trigonometrical part of the second half wave of (8) and (7) as symmetrical with that of the first half wave, that is, (7) and (8) to contain only the odd harmonics: $k = 2 i + 1$

Substituting (6) and (7) into (1) and (4) gives

$$e = B_0 + \epsilon^{-ct} \Sigma \{ [A_k (r - c L) - k q L A_k' - B_k] \sin k q t + [k q L A_k + A_k' (r - c L) - B_k'] \cos k q t\} \qquad (8)$$

$$\epsilon^{-ct} \Sigma \{ [A_k (1/C - c r - L [k^2 q^2 - c^2])$$

$$- k\,q\,A_k'\,(r - 2\,c\,L) + (c\,B_k + k\,q\,B_k')]\sin k\,q\,t$$
$$+ [k\,q\,A_k\,(r - 2\,c\,L) + A_k'\,(1/C - c\,r$$
$$- L\,[k^2 q^2 - c^2]\,) - (k\,q\,B_k - c\,B_k')\,]\cos k\,q\,t\} = 0 \tag{9}$$

$t = 0$ gives the terminal conditions; $i = 0$; $e = e_0$; thus, substituting into (7) and (8)

$$\Sigma\,A_k' = 0 \tag{10}$$

$$e_0 - B_0 = \Sigma\,\{k\,q\,L\,A_k + A_k'\,(r - c\,L) - B_k'\}$$

and by (10)

$$e_0 - B_0 = \Sigma\,\{k\,q\,L\,A_k - B_k'\} \tag{11}$$

As equation (9) must be an identity, its individual coefficients must vanish. This gives the $2\,n$ equations [where n = number of harmonics of the series in (6) and (7)]

$$\left.\begin{aligned} &A_k\,(1/C - c\,r - L\,[k^2 q^2 - c^2]\,) \\ &- k\,q\,A_k'\,(r - 2\,c\,L) + c\,B_k + k\,q\,B_k' = 0 \\ &k\,q\,A_k\,(r - 2\,c\,L) + A_k'\,(1/C - c\,r \\ &\quad - L\,[k^2 q^2 - c^2]\,) - k\,q\,B_k + c\,B_k' = 0 \end{aligned}\right\} \tag{12}$$

If the relation between the current i and the potential drop E across the gas circuit, is given by an equation

$$E = f\,(i) \tag{13}$$

then, substituting for E and for i the equations (6) and (7) into (13), gives an identity in $\sin k\,q\,t$, $\cos k\,q\,t$ and the constant term, and their individual coefficients must vanish. This gives $(2\,n + 1)$ further equations.

If the relation between E and i is given empirically, by curve or table, $(2\,n + 1)$ corresponding values may be chosen and so give the second set of $(2\,n + 1)$ terminal equations.

The $2\,n$ equations (12), the $(2\,n + 1)$ equations derived from (13), and the two equations (10) and (11) give a total of $(4\,n + 3)$ equations, for the determination of the $4\,n + 3)$ integration constants A_k, A_k', B_k, B_k', B_0, c and g.

A. Constant Resistance

If the resistance of the discharge circuit is constant, $= r$, that is, $E = 0$; B_0, B_k, and B_k' vanish, and by (12), all the A_k and A_k' also vanish, that is, there is no discharge, unless in one of the A_k, A_k' the individual coefficients in (13) vanish, and this A_k and A_k' thus becomes indefinite.

Assume this to be the case for $k = 1$. This assumption leaves the conditions general, as by choosing another value of k, the k merely enters as a factor into the q.

We have then, for $k = 1$, by equation (12)

$$1/C - c\,r - L\,(q^2 - c^2) = 0$$
$$r - 2\,L = 0$$

thus

$$\left.\begin{aligned} c &= \frac{r}{2\,L} \\ q &= \sqrt{\frac{1}{L\,C} - \frac{r^2}{4\,L^2}} \end{aligned}\right\} \tag{14}$$

by (10), $A' = 0$, and by (11)

$$A = \frac{e_0}{q\,L}$$

thus

$$\left.\begin{aligned} i &= \frac{e_0}{q\,L}\,\epsilon^{-\frac{r}{2L}t}\sin q\,t \\ e &= e_0\,\epsilon^{-\frac{r}{2L}t}\left\{\cos q\,t + \frac{r}{2\,q\,L}\sin q\,t\right\} \end{aligned}\right\} \tag{15}$$

These are the well-known equations of the condenser discharge through a circuit of constant resistance, inductance and capacity.

The ratio of the values of two successive half waves is constant

$$i_2/i_1 = \epsilon^{-\frac{r\pi}{2qL}} \tag{16}$$

that is, the discharge decreases in constant geometrical proportion.

An instance is plotted as curve I of Fig. 1, for the constants

$C = 10^{-6}$; $L = 10^{-2}$; $r = 50$; $e_0 = 20{,}000$, giving the equations:

Discharge Current

$$i = 207\,\epsilon^{-2500\,t}\sin 9685\,t$$

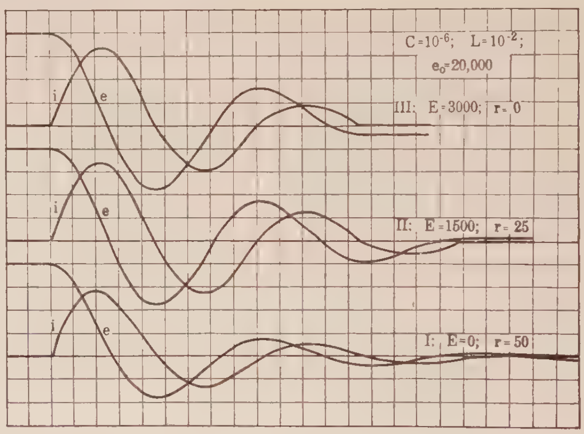


Fig. 1

Condenser Voltage

$$e = 20{,}000\,\epsilon^{-2500\,t}\,\{\cos 9685\,t + 0.258\sin 9685\,t\,\}$$

B. Constant Voltage Drop in Gas Circuit

$$E = \text{constant} = E_0$$

This gives $B_0 = E_0$; $B_k = 0 = B_k'$

Thus by the same reasoning, equation (12) gives

$$c = \frac{r}{2\,L}$$

$$q = \sqrt{\frac{1}{L\,C} - \frac{r^2}{4\,L^2}}$$

By (10); $A' = 0$

and by (11) $A = \dfrac{e_0 - E_0}{q\,L}$

Thus

$$\left.\begin{aligned} i &= \frac{e_0 - E_0}{q\,L}\,\epsilon^{-\frac{r}{2L}t}\sin q\,t \\ e &= E_0 + (e_0 - E_0)\,\epsilon^{-\frac{r}{2L}t}\left\{\cos q\,t + \frac{r}{2\,q\,L}\sin q\,t\right\} \end{aligned}\right\} \quad (17)$$

An instance is plotted as curve II, Fig. 1, for the constants

$C = 10^{-6}$; $L = 10^{-2}$; $r = 25$; $E = 1500$; $e_0 = 20{,}000$ giving the equations

$$\begin{aligned} i_1 &= 186.4\,\epsilon^{-1250t}\sin 9920\,t \\ i_2 &= -\,123\,\epsilon^{-1250t}\sin 9920\,t \\ i_3 &= +\,70.6\,\epsilon^{-1250t}\sin 9920\,t \\ i_4 &= -\,27.7\,\epsilon^{-1250t}\sin 9920\,t \\ i_5 &= 0 \\ e_1 &= 1500 + 18{,}500\,\epsilon^{-1250t}\{\cos 9920\,t + .126\sin 9920\,t\} \\ e_2 &= -\,1500 - 12{,}200\,\epsilon^{-1250t}\{\cos 9920\,t + .126\sin 9920\,t\} \\ e_3 &= +\,1500 + 7000\,\epsilon^{-1250t}\{\cos 9920\,t + .126\sin 9920\,t\} \\ e_4 &= -\,1500 - 2750\,\epsilon^{-1250t}\{\cos 9920\,t + .126\sin 9920\,t\} \\ e_5 &= +\,760 = \text{const.} \end{aligned}$$

In the special case that the ohmic resistance is negligible, $r = 0$, and all the energy dissipation occurs in a gas circuit of constant potential drop $E = E_0$, we have,

$$\left.\begin{aligned} c &= 0 \\ q &= \sqrt{\frac{1}{L\,C}} \end{aligned}\right\}$$

thus

$$\left.\begin{aligned} i &= (e_0 - E_0)\,z_o\sin q\,t \\ e &= E_0 + (e_0 - E_0)\cos q\,t \end{aligned}\right\} \quad (18)$$

where

$z_o = \sqrt{L/C}$ = surge impedance, or natural impedance of the circuit

In this case, at the end of the first half wave, we have,

$$e = e_1 = -\,(e_0 - 2\,E_0)$$

and the second half wave is given by

$$\left.\begin{aligned} i_2 &= -\,(e_0 - 3\,E_0)\,z_o\sin q\,t \\ e_2 &= -\,E_0 - (e_0 - 3\,E_0)\cos q\,t \end{aligned}\right\} \quad (19)$$

In this case, the difference between the maximum values of two successive half waves is constant:

$$\begin{aligned} e_1 - e_2 &= 2\,E_0 \\ i_1 - i_2 &= 2\,z_0\,E_0 \end{aligned} \quad (20)$$

that is, the discharge decreases in constant *arithmetical* porportion.

An instance is plotted as curve III of Fig. 1, for the constants:

$C = 10^{-6}$; $L = 10^{-2}$; $r = 0$; $E = 3000$; $e_0 = 20{,}000$, giving the equations:

$$\begin{aligned} i_1 &= 170\sin 10{,}000\,t \\ i_2 &= -\,110\sin 10{,}000\,t \\ i_3 &= +\,50\sin 10{,}000\,t \\ i_4 &= 0 \\ e_1 &= 3000 + 17{,}000\cos 10{,}000\,t \\ e_2 &= -\,3000 - 11{,}000\cos 10{,}000\,t \\ e_3 &= +\,3000 + 5000\cos 10{,}000\,t \\ e_4 &= -\,2000 = \text{const.} \end{aligned}$$

If $\quad e_0 = 2\,p\,E_0 \pm e_0'$ (21)

where p is the largest integer by which $2\,E_0$ divides into e_0, and leaves e_0' numerically (irrespective of the sign) less than E_0, that is, $e_0'^2 \leqq E_0^2$, p is the number of successive half waves of the discharge, and $\pm\,e'_0$ is the residual charge, remaining in the condenser, after the discharge stopped. That is, in this case, the condenser discharge does not consist of a (theoretically) infinite number of gradually decreasing half waves, which completely discharge it, but the discharge stops after a finite number of half waves, and does not completely discharge the condenser, but leaves a residual charge (as well-known in the discharges of condensers, such as Leyden jars, through a spark). This residual charge may be in the same direction or in the reverse direction of the initial charge e_0.

Thus in this case, the total discharge, $\int i\,d\,t = \theta$, is not constant and equal to the charge of the condenser: $\theta_0 = e_0\,C$, but may be more or less.

If $E_0 = > e_0/3$, only one half wave of discharge occurs, and the discharge thus is unidirectional, showing a similarity to the impulsive discharge. It differs therefrom by terminating sharply at a definite time, while the impulsive discharge tapers into infinity.

In the general case B, essentially the same conditions pertain; a finite number of half waves, and a residual charge remaining in the condenser. The decrement is neither geometrical (logarithmic) nor arithmetical.

C. Sine Wave Discharge

It is of special interest to investigate the conditions under which the successive half waves of discharge current and voltage are pure sines (except as regards to the exponential factor, and the discontinuity of the current slope), that is free of higher harmonics.

Then the trigonometric series ends with $k = 1$, and it is

$$i = A\,\epsilon^{-ct}\sin q\,t \quad (22)$$

$$E = B_0 - \epsilon^{-ct}\{B_1\sin q\,t - B_1'\cos q\,t\} \quad (23)$$

$$e = B_0 + \epsilon^{-ct}\{[A\,(r - c\,L) - B_1]\sin q\,t + [A\,q\,L + B_1']\cos q\,t\} \quad (24)$$

[For convenience, the sign B_1' has been chosen negative, so as to make B_1' positive for the usual form of the gas discharge.]

$2\,n + 1 = 3$ constants can then be chosen arbitrarily, that is, by experiment, etc., in the relation between i and E.

As such the following are preferably chosen:

The potential drop across the gas circuit at zero current at the beginning of the discharge: $E = E_0$ for $t = 0, i = 0$.

The potential drop across the gas circuit at zero current at the end of the discharge: $E = E_1$ for $q\,t = \pi, i = 0$.

The potential drop across the gas circuit for (approximately) maximum current, at the middle of the discharge: $E = E_m$ for $q\,t = \pi/2, i = i_m$.

In general, $E_m \leqq E_1 \leqq E_0$

This gives the equations, by substituting into (23)

$$\left.\begin{aligned} E_0 &= B_0 + B'_1 \\ E_1 &= B_0 - \delta^2 B_1' \\ E_m &= B_0 - \delta\,B_1 \\ \text{where}\quad \delta &= \epsilon^{-c\pi/2q} \end{aligned}\right\} \qquad (25)$$

thus

$$\left.\begin{aligned} B_0 &= \frac{\delta^2 E_0 + E_1}{1+\delta^2} \\ B_1 &= \frac{B_0 - E_m}{\delta} = \frac{\delta^2 E_0 + E_1 - (1+\delta^2) E_m}{\delta\,(1+\delta^2)} \\ B_1' &= \frac{E_0 - E_1}{1+\delta^2} \end{aligned}\right\} \qquad (26)$$

from equation (11) follows,

$$e_0 - B_0 = q\,L\,A + B_1'$$

thus

$$\left.\begin{aligned} A &= \frac{e_0 - B_0 - B_1'}{q\,L} = \frac{B}{q\,L} \\ \text{where}\quad B &= e_0 - E_0 \end{aligned}\right\} \qquad (27)$$

the equations (12) give,

$$\left.\begin{aligned} A\,[L\,(c^2 - q^2) - r\,c + 1/C] + [c\,B_1 - q\,B_1'] &= 0 \\ A\,q\,[r - 2\,c\,L] - [q\,B_1 + c\,B_1'] &= 0 \end{aligned}\right\}$$

and denoting,

$$\left.\begin{aligned} \frac{r}{L} &= a \\ \frac{1}{L\,C} &= k^2 \end{aligned}\right\} \qquad (28)$$

and substituting (27) for A, we have,

$$\left.\begin{aligned} B\,(c^2 - q^2 - c\,a + k^2) + q\,(c\,B_1 - q\,B_1' &= 0 \\ B\,(a - 2\,c) - (q\,B_1 + c\,B_1') &= 0 \end{aligned}\right\} \qquad (29)$$

From these two equations (29) follow the values of c and q, and thereby all the constants in i and e are evaluated.

As c and q enter into B_1 and B_1', through δ, equations (29) are best evaluated by approximation. That is, from (29) it follows that,

$$q = \frac{a\,B\,B_1}{B_1^2 + (2\,B + B_1')^2} + \sqrt{\frac{k^2\,B\,(2\,B + B_1')^2}{(B + B_1')\,[B_1^2 + (2\,B + B_1')^2\,]} + \left(\frac{a\,B\,B_1}{B_1^2 + (2\,B + B_1')^2}\right)^2 - \frac{a^2\,B^2}{B_1^2 + (2\,B + B_1')^2}} \qquad (30)$$

$$c = \frac{a\,B - q\,B_1}{2\,B + B_1'} \qquad (31)$$

Assuming first $q = k$ and $c = 0$, gives a first approximation of B_1 and B_1', and with these values of B and B_1', by equations (30) and (31) a first approximation of q and c is calculated, and this used in the same manner to get a second approximation of B_1 and B_1', and of q and c, and so on, until the approximation is sufficiently close, and this is usually obtained very rapidly.

Impulsive Discharge

Here q becomes imaginary, and the discharge thereby ceases to be oscillatory and becomes impulsive, when the term under the square root in (30) becomes negative. This is the case for

$$a^2 > k^2 \frac{B_1^2 + (2\,B + B_1')^2}{B\,(B + B_1')} \qquad (32)$$

or

$$r > 2\,z_0 \sqrt{1 + \frac{B_1^2 + B_1'^2}{4\,B\,(B + B_1')}} \qquad (33)$$

for $B_1 = 0$, $B_1' = 0$, this gives the usual equation: $r > 2\,z_0$.

In general, in a gas circuit B, B_1 and B_1' are positive, and thus the energy dissipation that occurs in the gas circuit does not lower the values of the ohmic resistance r, at which the discharge ceases to be oscillatory, but on the contrary, the presence of a gas circuit causes the discharge to remain oscillatory for values of the ohmic resistance r, greater than those at which otherwise the discharge would become impulsive.

Symmetrical Gas Discharge

If the discharge through the gas circuit is symmetrical, that is, the potential drop across the gas circuit, E, has the same value for decreasing as for increasing current i, or in other words, the discharge through the gas circuit has no time lag, then we have,

$$E_1 = E_0;\; B_1' = 0;\; B_0 = E_0;\; B_1 = \frac{E_0 - E_m}{\delta},$$

and

$$q = k\sqrt{\left\{\frac{1}{1 + \left(\frac{B_1}{2\,B}\right)^2} - \frac{a^2}{4\,k^2}\,\frac{1}{\left[1 + \left(\frac{B_1}{2\,B}\right)^2\right]^2} + \frac{a}{2}\,\frac{\frac{B_1}{2\,B}}{1 + \left(\frac{B_1}{2\,B}\right)^2}\right\}} \qquad (34)$$

$$c = \frac{a}{2} - q\,\frac{B_1}{2\,B} = \frac{a}{2}\,\frac{1}{1 + \left(\frac{B_1}{2\,B}\right)^2} - k\,\frac{B_1}{2\,B}\sqrt{\frac{1}{1 + \left(\frac{B_1}{2\,B}\right)^2} - \frac{a^2}{4\,k^2}\,\frac{1}{\left[1 + \left(\frac{B_1}{2\,B}\right)^2\right]^2}} \qquad (35)$$

$$\left.\begin{aligned} i &= \frac{e_0 - E_0}{q\,L}\,\epsilon^{-ct}\sin q\,t \\ E &= E_0 - (E_0 - E_m)\,\epsilon^{-ct + c\pi/2q}\sin q\,t \\ e &= E_0 + \epsilon^{-ct}\Big\{ (e_0 - E_0)\cos q\,L \\ &+ \left[\frac{r\,(e_0 - E_0)}{2\,q\,L} - \frac{E_0 - E_m}{2\,\delta}\right]\sin q\,L \Big\} \end{aligned}\right\} \tag{36}$$

Discharge with Negligible Ohmic Resistance

If the ohmic resistance of the discharge circuit is negligible, $r = 0$, that is, all the energy dissipation occurs in the gas circuit (as is probably usually the case with a lightning discharge, etc.), we have,

$$a = 0$$

$$\frac{c}{q} = \frac{-B_1}{2B + B_1}$$

$$q = k\,(2B + B_1')\sqrt{\frac{B}{(B + B_1')\,[B_1^2 + (2\,B + B_1')^2]}} \tag{37}$$

$$c = -\,k\,B_1\sqrt{\frac{B}{(B + B_1')\,[B_1^2 + (2\,B + B_1')^2]}} \tag{38}$$

that is, the exponent of the exponential term is positive, and the oscillation cumulative, thus increasing during the half wave—to drop however again discontinuously at the end of the half wave—to a value less than the preceding half wave, giving the decay of discharge, by the discontinuous voltage change at the current reversal, from $+E_1$ to $-E_0$.

In the condenser discharge through a constant ohmic resistance r, the exponent of the exponential term is,

$$c = \frac{r_0}{2\,L}$$

where r_0 = ohmic resistance.

Substituting in (38),

$$c = \frac{r_0}{2\,L}, \qquad k = \frac{1}{\sqrt{L\,C}}, \quad \text{gives,}$$

$$r_0 = -\frac{2}{\sqrt{L\,C}}\,B_1\sqrt{\frac{B}{(B + B_1')\,[B_1^2 + (2\,B + B_1')^2]}} \tag{39}$$

The gas discharge acts like an effective negative resistance of value r_0.

Symmetrical Gas Discharge of Negligible Ohmic Resistance

If the gas discharge is symmetrical, that is, in a symmetrical gas discharge of negligible ohmic resistance we have,

$r = 0$; $a = 0$, and $E_1 = E_0$, $B_1' = 0$; $B_0 = E_0$;

$$B_1 = \frac{E_0 - E_m}{\delta},$$

and,

$$q = \frac{k}{\sqrt{1 + \left(\dfrac{B_1}{2\,B}\right)^2}} = \frac{1}{\sqrt{L\,C\left(1 + \dfrac{E_0 - E_m}{2\,\delta\,(e_0 - E_0)}\right)^2}} \tag{40}$$

$$c = -\frac{k\,\dfrac{B_1}{2\,B}}{\sqrt{1 + \left(\dfrac{B_1}{2\,B}\right)^2}} = -\frac{E_0 - E_m}{2\,\delta\,(e_0 - E_0)}\,q \tag{41}$$

In this case, q is always real. Such a condenser discharge through a circuit of negligible ohmic resistance, but containing a symmetrical gas path, is always oscillatory, never impulsive, that is, unidirectional, though the oscillation may comprise one half wave only.

Decrement and Frequency

As a gas circuit acts like an effective negative resistance, it follows that in the circuit of a condenser discharged through a gas circuit a considerable ohmic resistance r_1 may exist, and the decrement of the circuit still be zero: $c = 0$.

The conditions of such a circuit of zero logarithmic decrement are,

$$c = 0; \quad \delta = 1.$$

$B = e_0 - E_0$; $B_0 = 1/2\,(E_0 + E_1)$; $B_1 = 1/2\,(E_0 + E_1 - 2\,E_m)$; $B_1' = 1/2\,(E_0 - E_1)$:

From (31) it follows that

$$q = a\,\frac{B}{B_1}$$

and, substituting this into (30), gives,

$$a = k\,\frac{B_1}{\sqrt{B\,(B + B_1')}}$$

$$q = \frac{k}{\sqrt{1 + \dfrac{B_1'}{B}}}$$

thus

$$r_1 = z_0\,\frac{E_0 + E_1 - 2\,E_m}{\sqrt{2\,(e_0 - E_0)\,(2\,e_0 - E_0 - E_1)}} \tag{42}$$

$$q = \frac{q_0}{\sqrt{1 + \dfrac{E_0 - E_1}{2\,(e_0 - E_1)}}} \tag{43}$$

where

$$z_0 = \sqrt{L/C}$$

$$q_0 = \frac{1}{\sqrt{L\,C}}$$

Thus, if in a condenser discharge circuit containing a gas path, the ohmic resistance $= r_1$ (42), the exponential decrement is zero, and the half waves of discharge are perfect sines. If the ohmic resistance r of the circuit is greater than r_1, $r > r_1$, the logarithmic decrement is positive, that is, the wave decays. If the

ohmic resistance r of the circuit is less than r_1, $r > r_1$, the logarithmic decrement is negative, that is cumulative, and the wave increases—to decrease however discontinuously at the end of the half wave by the change of the potential drop across the gas path, at the current reversal, from E_1 to $-E_0$.

For a symmetrical gas discharge we have, $E_1 = E_0$; $B_1' = 0$, thus,

$$r_1 = z_0 \frac{E_0 - E_m}{e_0 - E_0} \tag{44}$$

$$q = q_0 = \frac{1}{\sqrt{LC}} \tag{45}$$

It is interesting to note that, when the logarithmic decrement of the discharge oscillation disappears, due to the effective negative resistance of the gas path compensating for the constant ohmic resistance of the circuit, the frequency of the discharge—as given by $q = 2\pi f$—only then becomes equal to that of the circuit without energy dissipation, when the discharge is symmetrical. If however the gas circuit is not symmetrical, but the potential difference for rising current is greater than for decreasing current, in other words, if a time lag exists in the gas path, then the frequency of the oscillation is lowered by the asymmetrical nature of the gas path (43).

As the decrement c and the frequency constant q depend not only on the constants of the circuit and the gas path, but also on the initial condenser voltage e_0, it follows, that for the successive half waves of such a discharge, the decrement c and the frequency constant q are different. The value of c changes from positive to negative and increases negatively, that is, the damping effect of the successive half waves decreases, is replaced by a cumulative effect, and the latter indefinitely increases, until the discharge stops. The frequency in the successive half waves of discharge decreases, that is, the wave length increases, especially towards the end of the discharge, as seen from the illustration given below, and their equations, and the appended oscillograms.

Maximum Increment

In a condenser discharge through a gas circuit, the exponent of the decrement ϵ^{-ct} may be positive, ϵ^{+c_1t}, that is, the discharge is cumulative. The question arises under which conditions this cumulative effect is a maximum, that is, when c is a maximum negative value.

Equation (31) shows that this is the case for $a = 0$, that is, when $r = 0$, or there is no ohmic resistance, as was to be expected.

In this case we have,

$$c = -q \frac{B_1}{2B + B_1'}$$

thus, c is a maximum for $B_1' = 0$, or $E_1 = E_0$, a symmetrical discharge.

The maximum cumulative effect should occur with the symmetrical gas discharge of negligible ohmic resistance.

We have, then from (41)

$$c = -k \frac{\frac{B_1}{2B}}{\sqrt{1 + \left(\frac{B_1}{2B}\right)^2}}$$

$$= - \frac{\frac{E_0 - E_m}{2\delta(e_0 - E_0)}}{\sqrt{1 + \left(\frac{E_0 - E_m}{2\delta(e_0 - E_0)}\right)^2}} \tag{46}$$

which increases with increasing E_0 and decreasing E_m.

That is, the cumulative exponential decrement due to a gas path is the larger, the larger the potential drop across the gas path at zero current, and the smaller is the potential drop at maximum current, and approaches the final value for $E_m = 0$ and $E_0 = e_0$, of $c = -q_0$, or $r_0 = -z_0$.

That is, the effective negative resistance of the gas path approaches, as a maximum, the value of the surge impedance $z_0 = \sqrt{L/C}$ of the circuit.

Impulsive Discharge

The question arises, whether, and under what conditions the condenser discharge through a gas circuit may cease to be oscillatory, and becomes impulsive or unidirectional.

If, as is usually the case in a gas circuit, $e_0 > E_0 > E_1 > E_m$, B, B_1 and B_1' are positive, and by equation (33) the ohmic resistance r is given, which must be exceeded by the circuit, to become non-oscillatory, and this ohmic resistance is greater than in the absence of a gas path.

The further question arises, whether any condition of a gas circuit can be conceived, in which the discharge becomes impulsive by the energy dissipation in the gas circuit, irrespective of the ohmic resistance of the rest of the circuit. That is, whether a condenser discharge through a gas circuit of negligible constant ohmic resistance, but high energy dissipation in the gas path—such as a lightning flash—can ever be non-oscillatory.

If the ohmic resistance of the circuit is negligible, $r = 0$, and we have from (37),

$$q = \frac{k(2B + B_1')}{\sqrt{B_1^2 + (2B + B_1')^2}} \sqrt{\frac{B}{B + B_1'}}$$

$$c = -q \frac{B_1}{2B + B_1'}$$

q then can only become imaginary, that is, the discharge non-oscillatory, if

$$\frac{B}{B + B_1'}$$

becomes negative.

If $B_1' = 0$ in a symmetrical gas circuit, this is not possible, but

$$\sqrt{\frac{B}{B + B_1'}} = 1 ,$$

and, as stated after equation (**41**), such a discharge through a symmetrical gas circuit always is oscillatory, no matter how high the energy dissipation in the gas circuit, unless it is made non-oscillatory by constant series resistance (**33**).

The only condition, under which such a condenser discharge through a gas circuit of negligible ohmic resistance ceases to be oscillatory occurs when B_1' is negative and $- B_1' > B$, that is, by (**26**) and (**27**):

$$\frac{E_1 - E_0}{1 + 2\,\delta} > e_0 - E_0$$

Since $$E_1 > e_0 + \delta^2 (e_0 - E_0)$$
and as $E_0 < e_0$, otherwise the discharge would not start, it would mean a gas path in which the potential drop at the beginning of the discharge starts, for zero current, with a value E_0 less than the condenser voltage e_0, then decreases to E_m, and then increases to a value E_1, higher than the initial condenser voltage. In this case the discharge would obviously cease. It might be possible to experimentally create such conditions, by a slow vacuum discharge, producing a gas pressure and thereby increasing its potential drop, but in general, such would not occur. Unless a constant ohmic resistance of sufficiently high value is in series, a discharge through a gas circuit, such as a lightning flash, always must be oscillatory, no matter how great the energy dissipation, though the oscillation may contain one half wave only.

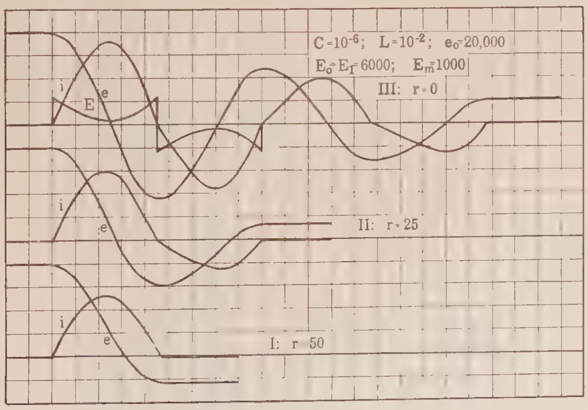


Fig. 2

Numerical Examples

As illustrations the following examples are given of some numerical values in Figs. 2 to 4, of the successive half waves of discharge, for the constants,

$$C = 10^{-6}; \qquad L = 10^{-2}; \qquad e_0 = 20{,}000$$

and in Fig. 2 for a symmetrical gas circuit varying from 6000 volts at zero current, to 1000 volts in the middle of the current wave, and back to 6000 volts at zero current, and for the three values of constant ohmic resistance.

Curve I. $r = 50$ ohms.

$$i_1 = 146\, \epsilon^{-600t} \sin 9600\, t$$
$$i_2 = 0$$
$$e_1 = 6000 + \epsilon^{-600t}\{900 \sin 9600\, t + 14{,}000 \cos 9600\, t\}$$
$$e_2 = -5500 = \text{const.}$$
$$E_1 = 6000 - 5520\, \epsilon^{-600t} \sin 9600\, t$$
$$E_2 = 0$$

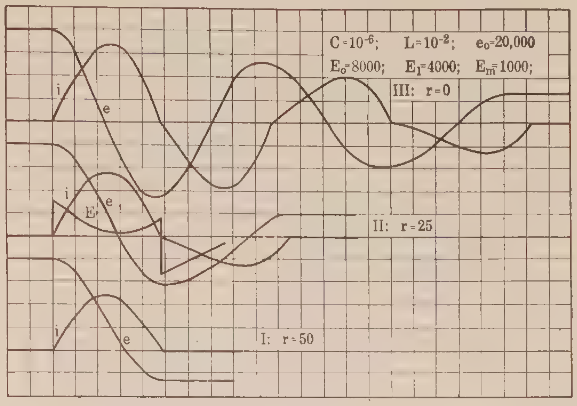


Fig. 3

Curve II. $r = 25$ ohms.

$$i_1 = 140\, \epsilon^{+435t} \sin 10{,}000\, t$$
$$i_2 = -39.3\, \epsilon^{+2780t} \sin 9900\, t$$
$$i_3 = 0$$
$$e_1 = 6000 + \epsilon^{+435t}\{-570 \sin 10{,}000\, t + 14{,}000 \cos 10{,}000\, t\}$$
$$e_2 = -6000 - \epsilon^{2780t}\{-1140 \sin 9900\, t + 3900 \cos 9900\, t\}$$
$$e_3 = +3450 = \text{const.}$$
$$E_1 = 6000 - 4680\, \epsilon^{+435t} \sin 10{,}000\, t$$
$$E_2 = -6000 + 3220\, \epsilon^{+2780t} \sin 9900\, t$$
$$E_3 = 0$$

Curve III. $r = 0$.

$$i_1 = 142\, \epsilon^{+1420t} \sin 9900\, t$$
$$i_2 = -102\, \epsilon^{+1830t} \sin 9830\, t$$
$$i_3 = +62\, \epsilon^{+2600t} \sin 9650\, t$$
$$i_4 = -23\, \epsilon^{+4800t} \sin 8750\, t$$
$$i_5 = 0$$
$$e_1 = 6000 + \epsilon^{+1420t}\{-2000 \sin 9900\, t + 14{,}000 \cos 9900\, t\}$$
$$e_2 = -6000 - \epsilon^{+1830t}\{-1870 \sin 9830\, t + 10{,}000 \cos 9830\, t\}$$
$$e_3 = +6000 + \epsilon^{2600t}\{-1660 \sin 9650\, t + 6000 \cos 9650\, t\}$$
$$e_4 = -6000 - \epsilon^{+4800t}\{-1120 \sin 8750\, t + 2000 \cos 8750\, t\}$$
$$e_5 = +5200 = \text{const.}$$
$$E_1 = 6000 - 4000\, \epsilon^{+1420t} \sin 9900\, t$$
$$E_2 = -6000 + 3740\, \epsilon^{+1830t} \sin 9830\, t$$
$$E_3 = +6000 - 3270\, \epsilon^{+2600t} \sin 9650\, t$$
$$E_4 = -6000 + 2220\, \epsilon^{+4800t} \sin 8750\, t$$
$$E_5 = 0$$

For the same values $C = 10^{-6}$; $L = 10^{-2}$ and $e_0 = 20{,}000$, Fig. 3 gives the discharge waves through an unsymmetrical gas circuit, varying from 8000 volts at zero current, to 1000 volts in the middle of the current wave, and then back to 4000 volts at zero current, and for the three values of constant ohmic resistance.

Curve I. $r = 50$ ohms.

$$i_1 = 131\, \epsilon^{-450t} \sin 9180\, t$$
$$i_2 = 0$$
$$e_1 = 5840 + \epsilon^{-450t} \{720 \sin 9180\, t + 14{,}160 \cos 9180\, t\}$$
$$e_2 = 6330 = \text{constant}$$
$$E_1 = 5840 - \epsilon^{-450t} \{5250 \sin 9180\, t - 2160 \cos 9180\, t\}$$
$$E_2 = 0$$

Curve II. $r = 25$ ohms.

$$i_1 = 129\, \epsilon^{+545t} \sin 9300\, t$$
$$i_2 = -29.3\, \epsilon^{+3450t} \sin 7900\, t$$
$$i_3 = 0$$
$$e_1 = 6180 + \epsilon^{+545t} \{-830 \sin 9300\, t + 13820 \cos 9300\, t\}$$
$$e_2 = -7200 - \epsilon^{+3450t} \{-1340 \sin 7900\, t + 3120 \cos 7900\, t\}$$
$$e_3 = +5100 = \text{const.}$$
$$E_1 = 6180 - \epsilon^{+545t} \{4740 \sin 9300\, t - 1820 \cos 9300\, t\}$$
$$E_2 = -7200 + \epsilon^{+3450t} \{3080 \sin 7900\, t - 790 \cos 7900\, t\}$$

Curve III. $r = 0$.

$$i_1 = 129\, \epsilon^{+1550t} \sin 9310\, t$$
$$i_2 = -90.5\, \epsilon^{+2060} \sin 9070\, t$$
$$i_3 = +55\, \epsilon^{+2880t} \sin 8500\, t$$
$$i_4 = -20.5\, \epsilon^{+4500t} \sin 7320\, t$$
$$i_5 = 0$$
$$e_1 = 6500 + \epsilon^{+1550t} \{-5250 \sin 9310\, t + 13{,}500 \cos 9310\, t\}$$
$$e_2 = -6700 - \epsilon^{+2060t} \{-5860 \sin 9070\, t + 9500 \cos 9070\, t\}$$
$$e_3 = +7000 + \epsilon^{+2880t} \{-5110 \sin 8500\, t + 5700 \cos 8500\, t\}$$
$$e_4 = -7500 - \epsilon^{+4500t} \{-3300 \sin 7320\, t + 2000 \cos 7320\, t\}$$
$$e_5 = +6300 = \text{const.}$$
$$E_1 = 6500 - \epsilon^{+1550t} \{4250 \sin 9310\, t - 1490 \cos 9310\, t\}$$
$$E_2 = -6700 + \epsilon^{+2060t} \{4000 \sin 9070\, t - 1310 \cos 9070\, t\}$$
$$E_3 = +7000 - \epsilon^{+2880t} \{3530 \sin 8500\, t - 1030 \cos 8500\, t\}$$
$$E_4 = -7500 + \epsilon^{+4500t} \{2300 \sin 7320\, t - 500 \cos 7320\, t\}$$
$$E_5 = 0.$$

As seen, the number of half waves of the discharge under these conditions of a high open-circuit voltage of the gas path, varies from one at the constant resistance of 50 ohms, to four with no ohmic resistance in circuit.

Fig. 4 shows the discharge curves, for the same constants $C = 10^{-6}$; $L = 10^{-2}$; $e_0 = 20{,}000$, for a low ohmic resistance, $r = 10$, and through an unsymmetrical gas path of lower voltage; from $E_0 = 3000$ volts at zero current, down to $E_m = 500$ volts for larger currents, and up again to $E_1 = 1000$ volts for zero current.

We have,

$$i_1 = 175\, \epsilon^{-67t} \sin 9720\, t$$
$$i_2 = -131\, \epsilon^{+66t} \sin 9650\, t$$
$$i_3 = +93.5\, \epsilon^{+278t} \sin 9510\, t$$
$$i_4 = -61.6\, \epsilon^{+626t} \sin 9270\, t$$
$$i_5 = +34.9\, \epsilon^{+1315t} \sin 8840\, t$$
$$i_6 = -12.1\, \epsilon^{+3250t} \sin 7450\, t$$
$$i_7 = 0$$
$$e_1 = 1990 + \epsilon^{-67t} \{120 \sin 9720\, t + 18{,}010 \cos 9720\, t\}$$
$$e_2 = -2010 - \epsilon^{+66t} \{-90 \sin 9650\, t + 13{,}610 \cos 9650\, t\}$$
$$e_3 = +2050 + \epsilon^{+278t} \{-285 \sin 9510\, t + 9840 \cos 9510\, t\}$$
$$e_4 = -2110 - \epsilon^{+626t} \{-450 \sin 9270\, t + 6620 \cos 9270\, t\}$$

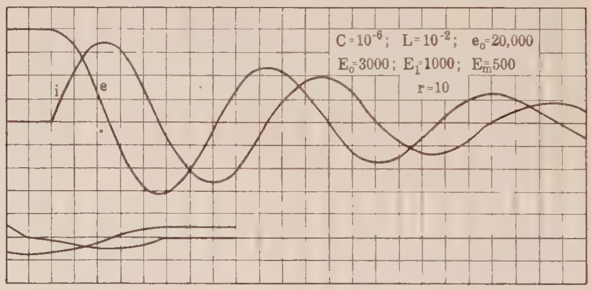


Fig. 4

$$e_5 = +2230 + \epsilon^{+1315t} \{-570 \sin 8840\, t + 3850 \cos 8840\, t\}$$
$$e_6 = -2600 - \epsilon^{+3250t} \{-570 \sin 7450\, t + 1300 \cos 7450\, t\}$$
$$e_7 = +2500 = \text{const.}$$
$$E_1 = 1990 - \epsilon^{-67t} \{1510 \sin 9720\, t - 1010 \cos 9720\, t\}$$
$$E_2 = -2010 + \epsilon^{+66t} \{1490 \sin 9650\, t - 990 \cos 9650\, t\}$$
$$E_3 = +2050 - \epsilon^{+278t} \{1480 \sin 9510\, t - 950 \cos 9510\, t\}$$
$$E_4 = -2110 + \epsilon^{+626t} \{1450 \sin 9270\, t - 895 \cos 9270\, t\}$$
$$E_5 = +2230 - \epsilon^{+1315t} \{1380 \sin 8840\, t - 775 \cos 8840\, t\}$$
$$E_6 = -2600 + \epsilon^{+3250t} \{1080 \sin 7450\, t - 410 \cos 7450\, t\}$$
$$E_7 = 0.$$

It is interesting to note that in the successive half waves of discharge through a gas circuit, especially an unsymmetrical one, under these conditions the frequency decreases, that is, the wave length increases,

by over 30 per cent between the last and the first half wave.

The exponential decrement steadily decreases, and thus changes from a decrement in the first half wave, to an increment of increasing amplitude in the successive half waves. If the ohmic resistance is small, the first half wave shows an increment.

D. Non-Sinoidal Discharge

As a further illustration there is shown, in Fig. 5, the first half wave of a discharge carried out to the third harmonic, through a symmetrical gas path and a constant ohmic resistance of such value as to make the decrement vanish, that is, to give $c = 0$; for the constants: $C = 10^{-6}$; $L = 10^{-2}$; $e_0 = 20{,}000$, and for the voltages of the gas path given as

E_0 = 6000 volts at zero current, at the beginning and the end of the half wave,

E_m = 1000 volts in the middle of the half wave, and

E = 2000 volts at 30 degrees after the beginning and before the end of the half wave.

The values E_0, E_m and E_2 substituted into equation (**6**) give five expressions for the determination of the

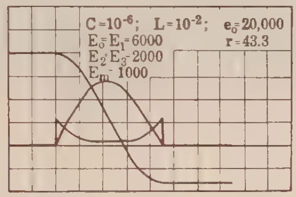


Fig. 5

five constants, B_0, B_1, B_1', B_3, B_3'. The four equations (**12**) express the values A_1, A_1', A_3, A_3' in the values of B, and, substituted into equations (**10**) and (**11**), give two equations for the determination of q and r, by approximation.

This gives the value of constant ohmic resistance as $r = 43.3$ ohms, and the discharge equations,

$$i = A_1 \sin q\,t + A_1' \cos q\,t + A_3 \sin 3\,q\,t$$
$$+ A_3' \cos 3\,q\,t = 139 \sin 9946\,t + 3.6 \cos 9946\,t$$
$$+ .2 \sin 29{,}838\,t - 3.6 \cos 29{,}838\,t$$

$$e = B_0 \Sigma \{ (r\,A_k - k\,q\,L\,A_k' - B_k) \sin k\,q\,t$$
$$+ (k\,q\,L\,A_k + r\,A_k') \cos k\,q\,t \} = 6000$$
$$- 330 \sin 9946\,t + 14{,}100 \cos 9946\,t$$
$$+ 80 \sin 29{,}838\,t - 100 \cos 29{,}838\,t$$

$$E = B_0 - B_1 \sin q\,t - B_3 \sin 3\,q\,t = 6000$$
$$- 6000 \sin 9946\,t - 1000 \sin 29{,}838\,t.$$

Volt-Ampere Characteristics

Fig. 6 gives the volt-ampere characteristics (of the first half wave) of the preceding figures, that is, the potential drop of the gas circuit E, as ordinate, with the current as abscissas (in a fraction of its maximum value).

Line $C\,D$ (**2**) gives the E to i relation of the symmetrical gas circuit of Fig. 2.

Curve E-D-F (**3**) gives the unsymmetrical circuit of figure 3, with $E\,D$ for increasing, $D\,F$ for decreasing current.

Curve C (**5**) D gives the E to i characteristic of the discharge. Fig. 5, containing the third harmonic.

For comparison, $A\,B$ (r) is the volt-ampere characteristic of a constant ohmic resistance, and $C\,B$ (1) that of a gas path of constant voltage.

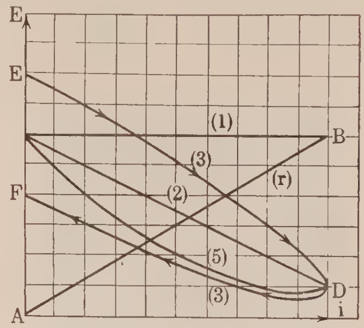


Fig. 6

E. Asymmetrical or Unidirectional Conductor

The volt-ampere characteristics of gaseous conductors very often depend on the direction of the current flow, that is, the potential drop across the conductor, and its variations with the current are entirely different for the current flowing in one direction, from that of the current flowing in the reverse direction,—often very much lower. Such for instance is the case in the vacuum tube with one hot and one cold electrode, or a vacuum tube with one cold carbon electrode and one ionized mercury electrode. In this case the potential drop across the tube is very low and approximately constant if the incandescent or ionized electrode is

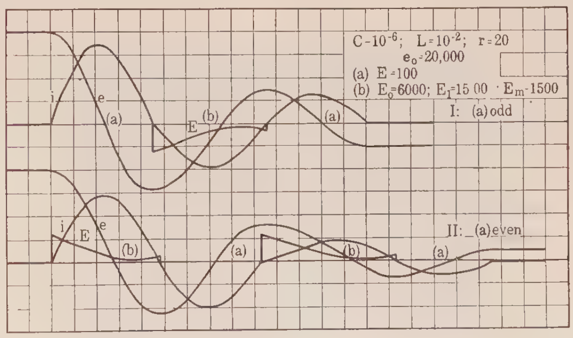


Fig. 7

negative, and the potential drop may be very high, especially at zero current in the beginning of the discharge, if the cold electrode is negative.

Since the equations of the condenser discharge through a gas circuit have to be calculated for every half wave separately, the calculation of the condenser discharge through such a unidirectional or "rectifying" conductor is the same, the only difference being that for alternate half waves of discharge, different constants are used.

For example let, for the current in one direction, the gaseous circuit consume a constant voltage

$$E = E_0 = 100 \text{ volts} \quad \textbf{(a)}$$

And for the current in the reverse direction, consume a voltage varying from

$$E = E_0 = 6000 \text{ volts} \quad \textbf{(b)}$$

at zero current, to

$$E = E_m = 1500 \text{ volts} \quad \textbf{(b)}$$

in the middle of the discharge, and reaching again

$$E = E_1 = 1500 \text{ volts} \quad \textbf{(b)}$$

for zero current at the end of the discharge.

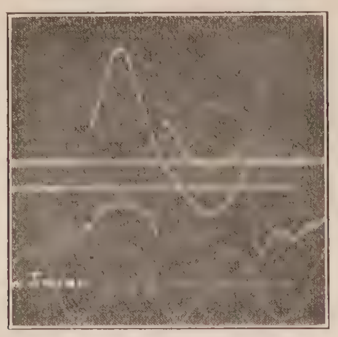


Fig. 8

Then the even half waves of the discharge are calculated with the one, and the odd half waves with the other set of constants, (a) or (h), as shown in Sections B or C.

Fig. 7 shows the two discharge curves, for

$$e_0 = 20{,}000; \quad C = 10^{-6}; \quad L = 10^{-2}; \quad r = 20$$

and, in Curve I for the first half wave being in the direction of the conduction of the gas path, (a), while in Curve II the first half wave of the current is in such direction that the gas circuit offers a high opposing voltage (b).

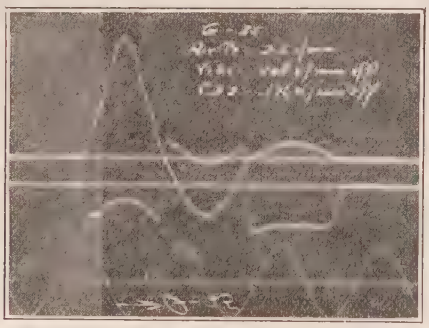


Fig. 9

The equations of the discharge then are:

Curve I. High Conductivity during Odd Half Waves.

$$i_1 = 200\ \epsilon^{-1000t} \sin 9950\, t$$
$$i_2 = -\ 93.3\ \epsilon^{+185t} \sin 8900\, t$$
$$i_3 = +\ 73\ \epsilon^{-1000t} \sin 9950\, t$$
$$i_4 = 0$$
$$e_1 = 100 + \epsilon^{-1000t} \{2000 \sin 9950\, t + 19{,}900 \cos 9950\, t\}$$
$$e_2 = -\ 3830 - \epsilon^{+185t} \{-\ 225 \sin 8900\, t + 10{,}470 \cos 8900\, t\}$$
$$e_3 = +\ 100 + \epsilon^{-1000t} \{730 \sin 9950\, t + 7270 \cos 9950\, t\}$$
$$e_4 = -\ 5160 = \text{const.}$$
$$E_1 = 100$$
$$E_2 = -\ 3830 + \epsilon^{+185t} \{2260 \sin 8900\, t - 2180 \cos 8900\, t\}$$
$$E_3 = +\ 100$$
$$E_4 = 0.$$

Curve II. High Conductivity during Even Half Waves.

$$i_1 = 151\ \epsilon^{-237t} \sin 9270\, t$$
$$i_2 = -\ 114\ \epsilon^{-1000t} \sin 9950\, t$$
$$i_3 = +\ 28\ \epsilon^{+2060t} \sin 7530\, t$$
$$i_4 = -\ 33.6\ \epsilon^{-1000t} \sin 9950\, t$$
$$i_5 = 0$$
$$e_1 = 3660 + \epsilon^{-237t} \{425 \sin 9270\, t - 16{,}340 \cos 9270\, t\}$$

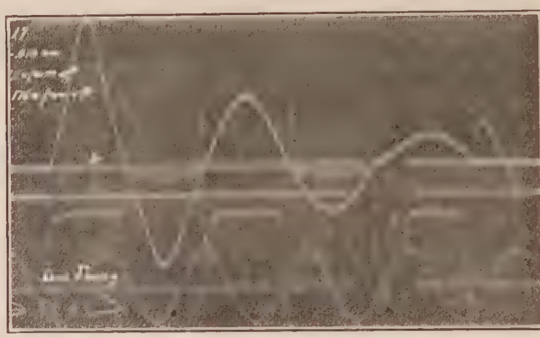


Fig. 10

$$e_2 = -\ 100 - \epsilon^{-1000t} \{1140 \sin 9950\, t + 11{,}350 \cos 9950\, t\}$$
$$e_3 = +\ 4650 + \epsilon^{+2060t} \{-\ 935 \sin 7530\, t + 3450 \cos 7530\, t\}$$
$$e_4 = -\ 100 - \epsilon^{-1000t} \{335 \sin 9950\, t + 3340 \cos 9950\, t\}$$
$$e_5 = +\ 2300 = \text{const.}$$
$$E_1 = 3660 - \epsilon^{-237t} \{2240 \sin 9270\, t - 16{,}340 \cos 9270\, t\}$$
$$E_2 = -\ 100$$
$$E_3 = 4650 - \epsilon^{+2060t} \{2070 \sin 7530\, t - 1350 \cos 7530\, t\}$$
$$E_4 = -\ 100$$
$$E_5 = 0.$$

It is interesting to note, that not only the amplitudes and the decrements of the odd and of the even half waves are different, but also the frequency or duration of the half waves.

As the calculated curves given in the preceding section show a number of characteristics different from the usual oscillating discharge curves, a series of oscillograms was taken of such an inductive condenser discharge through a gas circuit. Three of these oscillograms are given in Figs. 8, 9 and 10.

The gas circuit consisted of a vacuum tube of 1 1/2 in. diameter and 36 in. length, with tungsten electrodes.

The inductance was measured as $L = 7.4$ h., the capacity $1.7\ \mu$f; the ohmic resistance of the circuit

$r = 34.5$ ohms, and the initial voltage of the condenser discharge was $e_0 = 10{,}000$ volts.

These oscillograms very decidedly show the characteristics calculated in Figs. 2 and 4:

A discontinuity in the slope of the discharge current at the reversal.

The wave shape of the current, characteristic of a cumulative discharge, that is, decreasing more abruptly than increasing (the reverse of the usual damped discharge.)

The gradual increase of the wave length, that is, decrease of q.

These three characteristics becoming more pronounced towards the end of the oscillation.

The residual charge left in the condenser—in this case gradually leaking out through the oscillograph shunt.

The oscillograms give the discharge current, the voltage across the vacuum tubes, and a 60-cycle timing wave.

In Fig. 8, the air pressure in the vacuum tube was 5 mm. of mercury. The oscillation consisted of two half waves, of maximum currents $i = 6.25$ and 2.85 amperes, and wave length constants $q = 176$ and 164. The second half wave of voltage gives $E_0 = 4150$; $E_1 = 3080$; $E_m = 1530$.

In Fig. 9, the air pressure was 3.5 mm. of mercury. Three half waves occurred, with maximum currents $i = 6.7$; 3.17; $.88$ amperes, and wave length constants $q = 228$; 218; 203. The second wave gave $E_0 = 2830$; $E_1 = 2430$; $E_m = 1480$.

In Fig. 10, the air pressure was 0.01 mm. of mercury, and the voltage curves therefore are of materially different appearance. Five half waves occurred of the maximum currents $i = 8.2$; 5.42; 3.75; 2.53; 1.58 amperes, and the wave length constants $q = 250$; 242; 230; 215; 199. The second half wave gave $E_0 = 3030$; $E_1 = 2470$; $E_m = 530$.

DEVELOPED WATER POWER OF THE UNITED STATES

The U. S. Geological Survey, in 1921, made a compilation of data showing the developed water power in the United States in plants of 100 horse power or more. The data were collected by district engineers of the Survey by correspondence or by personal visits to the plants. The results of the compilation are considered to be reliable and show that at present there are in the United States 3116 water-power plants of 100 horse power or more, with a total capacity of installed water wheels of 7,852,948 horse power. Of this total 79 per cent is in public-utility plants and 21 per cent in manufacturing plants.

New York still maintains its position as the leading State with 1,291,857 horse power; California is second, with 1,149,099 horse power; Washington is third, with 454,356 horse power; Maine closely follows in fourth place, with 449,614 horse power; and Montana is fifth with 344,420 horse power.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

AUTOMOBILE HEADLIGHTING

At the 15th Annual Convention of the Illuminating Engineering Society held last September a paper "Determinations by Various Observers of Desired Road Illumination from the Automobile Headlamps", by H. H. Magdsick and R. N. Falge, was presented. This paper covered the results of a systematic investigation of the lighting requirements under various conditions of road surface, contour, street lighting, boundaries, speed, weather, etc., for a large number of observers. Special equipment controllable by the observer in the moving car enables him to get just the distribution and intensity of light requisite for the given conditions. The fundamental data contained in this paper have proved of much interest and value to motor car, headlamp and cover glass manufacturers, state officials and others interested in motor car lighting. This investigation offers more definite criteria than were formerly available and provides reliable data against which to check the performance of given designs of equipment.

STATE REGULATION OF MOTOR CAR HEADLAMPS

Regulations governing the use of automobile headlamps in one way or another are in force in 37 states of the Union. These regulations cover a number of the conditions experienced in the use of head-lamps on automobiles. Most of them are designed either to eliminate glare by limiting the height of the beam, to protect against glare by requiring the use of dimmers or other device, to provide safe road illumination by specifying the distance ahead at which substantial objects shall be revealed or prevent accident by specifying the distance ahead at which the head-lamps are required to be visible.

Requirements of this character are somewhat ambiguous. There may be some question as to just what the limits of the beam are: the distance at which a substantial object is revealed depends upon the size and color of such an object, the background, the atmospheric conditions, the individual's eyes, their adaptation, etc. The desired ends can be accomplished with much more certainty and the administration of the regulations greatly facilitated by a definite statement of the maximum candle-power which may be directed at such angles as to interfere with the approaching driver and the minimum intensity which must be directed to the road to insure a safe driving light. The Illuminating Engineering Society and the Society of Automotive Engineers are the sponsors for regulations of this kind in the form shown in Fig. 1. The tendency in new legislation is to adopt this system; in thirteen states the regulations are already based upon it:

California	Maine	Pennsylvania
Connecticut	Maryland	Utah
Indiana	Nebraska	Vermont
Iowa	New York	Wisconsin
	Ohio	

The values given in Fig. 1 apply for all except California and Pennsylvania, which require only 1200 candle-power between points "*a*" and "*b*". The position of the point "*b*" varies slightly; in some of the regulations it is taken as half way between the level of the head-lamps and the road, that is, the ray projected through that point strikes the level road surface 200 feet ahead of the car.

A fourteenth state, Massachusetts, has adopted the same system with somewhat different designated points and values as shown in Fig. 2. It will be noted that a materially higher road illumination and a wider spread of beam are required than is the case in the other states. The values of illumination desired by the large

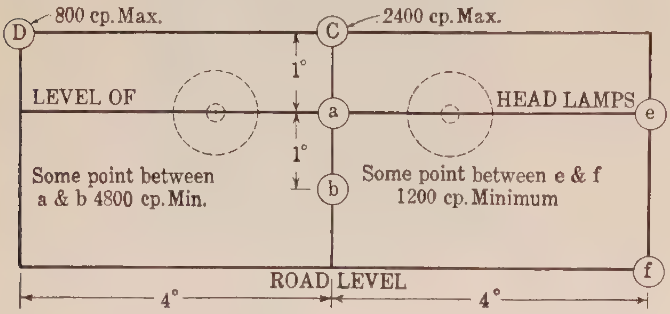


Fig. 1—Limiting C. P. Values
Measured on vertical plane 100 ft. ahead of car.

number of observers in the tests described in the preceding item, would seem to indicate in favor of the Massachusetts regulations, and raise the question as to whether the values of earlier regulations are sufficiently high.

In some of these fourteen states the administration of the regulation goes no further than the requirement that every car must be equipped with a cover glass or device properly focused and aimed, which is of a type approved by the state authority on the basis of a laboratory test. All of the states except Wisconsin issue lists of devices which are so approved. In Wisconsin, it is merely provided that the motorists must have his car equipped so that his lighting at all times complies with these regulations. Various test stations are provided where he may be sent to determine whether he is complying with the law, and various garages and dealers are designated by the state as competent to equip and adjust head-lamps under the regulations. In several of the other states the approved device provision is supplemented by checking up in service under the same performance specification either on the road or at special test stations.

In giving lists of approved devices the authorities in some states indicate the maximum candle-power of the incandescent lamps which may be used with each device. As a rule in approving these devices the state has further required that they pass the regulations when equipped with the standard 15-candle-power vacuum and the 21-candle-power gas-filled lamps. A number of the states make a general ruling that no lamp above a certain candle-power shall be employed in any device:

Arizona	32 c. p. max.	Nebraska	24 c. p. max.
California	32 c. p. max.	New York	24 c. p. max.
Connecticut	24 c. p. max.	Ohio	32 c. p. max.
Iowa	32 c. p. max.	Pennsylvania	32 c. p. max.
Maine	32 c. p. max.	Utah	32 c. p. max.
Maryland	32 c. p. max.	Washington	27 c. p. max.
Massachusetts	21 c. p. only	West Virginia	32 c. p. max.
Minnesota	32 c. p. max.	Wisconsin	32 c. p. max.
Mississippi	36 c. p. max.		

Much confusion has arisen among car owners, the automotive trade and miniature lamp agents as a result of such provision. Many times it has been assumed that a lamp of the highest candle-power permitted was thereby also recommended for use. This is far from being the case. Substantially all of the headlighting equipments now on the market were designed for use with the 21-candle-power gas-filled lamp primarily and give the best results with this lamp. Results with lamps of higher candle-power are often inferior due to larger size of filament causing greater vertical spread of beam, heavier drain on the battery, etc. The Massachusetts officials, realizing the disadvantages of the higher candle-power lamp, as well as the far greater candle-power depreciation occurring with the vacuum lamps, included in their regulations the requirement that only 21-candle-power gas-filled lamps may be employed.

A strict interpretation of the regulations would in some of the states make it illegal at any time to use a controllable headlight. Massachusetts provides that any controllable device must comply with the law in

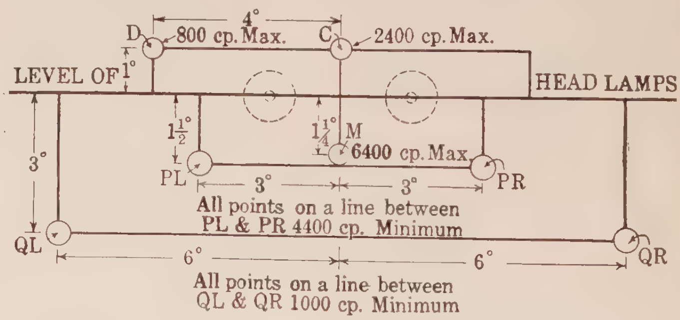


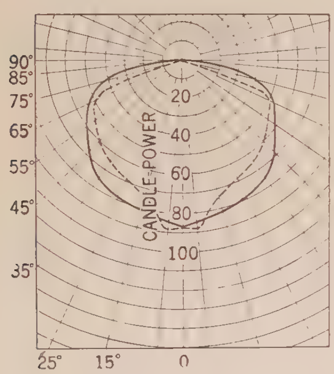
Fig. 2—Limiting C. P. Requirements
Measured on vertical plane 100 ft. ahead of car.

its "up" position and in one or two of the other states the enforcement officers have in their interpretation of their regulations barred any controllable equipment. On the other hand, Ohio is typical of the states which, with similar laws, do not bar the controllable device but simply leave it to the car driver never to use more light than the law allows above the horizontal when there is an approaching driver or pedestrian in sight. In other words, the same rational attitude is adopted toward the controllable device as in connection with speed. The man on the country highway violates the speed regulations with impunity so long as he does not endanger other persons or property. There is no

reason why the utility of his car should be any more restricted by limiting him to lighting, with which he can under most conditions not proceed safely at any more than 25 miles per hour. As the speed increases the need for additional light above the horizontal becomes rapidly more urgent in order to reveal the road far enough ahead for the safety of the driver and his passengers as well as of pedestrians on the road. Devices of the character which employ two reflectors and two lamps in each unit, or in which the beam can be tilted by moving all or a part of the reflector, are needed for safe driving if a car owner is to obtain reasonable utility of his car in country driving.

NEW MILL-TYPE LAMPS IN REFLECTORS AND WIRE GUARDS

A few months ago a new mill-type lamp was made available to users of incandescent lamps. This mill-type lamp is even more substantial than its predecessors, being designed better to withstand the hard usage to which mill-type lamps are subjected. In order to make this lamp more substantial, it was necessary to use a ring-type filament, a relatively short light-center length and a new shape in the tipless pear shaped bulb. Since the distribution of light and the reflector efficiency depend upon the lamp filament being in a certain position



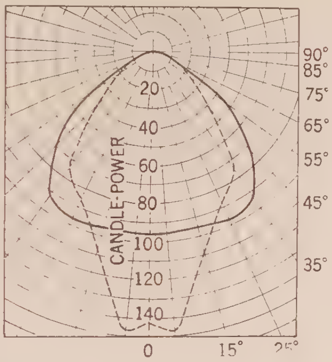


FIG. 1—PORCELAIN ENAMELED SHALLOW DOME—12 IN. DIAMETER

- - - - - - p-19 mazda mill-type lamp in reuglar "O" holder position—reflector efficiency 58 per cent.

———— p-19 mazda mill-type lamp with standard 1 3/8-in. socket extension—reflector efficiency 76 per cent.

FIG. 2—PORCELAIN ENAMELED BOWL REFLECTOR -7½-IN. DIAMETER

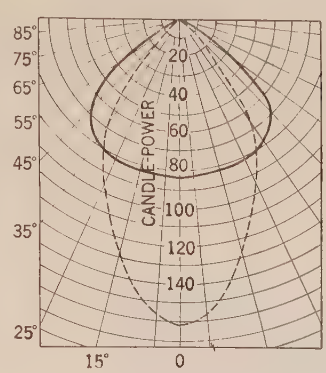
- - - - - - p-19 mazda mill-type lamp in regular "O" holder position—reflector efficiency 46 per cent.

———— p-19 mazda mill-type lamp with standard 1 3/8-in socket extension—reflector efficiency 61 per cent.

with respect to the reflector surface, some trouble may be experienced in adapting the new lamp to reflectors which were designed for the earlier straight-side bulbs. Some difficulty may also be experienced in using the new lamp in the styles of wire guards now commonly used.

If these new mill-type lamps are merely placed in reflectors designed for regular lamps, the shortened light-center length throws the filament too high up in the neck of the reflector. This results in a freakish distribution of light and a tendency to concentrate the light too much in a small spot beneath the reflector. The dotted curves of Figs. 2, 3 and 4 show this concentrating effect.

By using a standard 1⅜-inch socket extension in each of the four standard reflectors shown, the pocketing of the light in the neck of the reflector can be minimized and the distribution of light brought back almost to



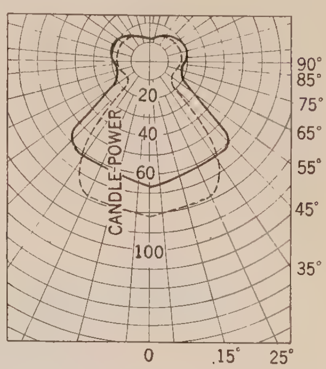


FIG. 3—ALUMINUM-FINISH BOWL REFLECTOR—7½-IN. DIAMETER

- - - - - - p-19 mazda mill-type lamp in regular "O" holder position—reflector efficiency 39 per cent.

———— p-19 mazda mill-type lamp with standard 1 3/8-in. socket extension—reflector efficiency 50 per cent.

FIG. 4—LIGHT-DENSITY OPAL BOWL REFLECTOR—7-in. DIAMETER

- - - - - - p-19 mazda mill-type lamp on regular "O" holder position—reflector efficiency 69 per cent.

———— p-19 mazda mill-type lamp with standard 1 3/8-in. socket extension—reflector efficiency 80 per cent.

normal, shown by the solid line curves. The reflector efficiencies are thereby very appreciably increased. The captions under the curves indicate the equipment used in the reflector and the resulting efficiency:

Reflector Using P-19 Mill Type Lamp	Without Socket Extension	With Socket Extension
Porcelain-Enameled Shallow Dome	58 per cent	76 per cent
Porcelain-Enameled Bowl	46 per cent	61 per cent
Aluminum Finish Bowl	39 per cent	50 per cent
Light Density Opal Bowl	69 per cent	80 per cent

Because many of the wire guards now in use were designed to fit the 16 and 32 candle-power lamps, they do not fit the new P-19 lamps. To be effective, the outer strands of a guard should *clear* the lamp bulb on all sides so that knocks and shocks may be absorbed rather than transmitted to the glass bulb.

Many of the wire guard manufacturers are now either designing guards to fit the new pear shaped bulbs or remodeling their old ones to fit this lamp. In most of the cases where the guards touch the glass of the bulb near the neck it is possible to bend the wire strands to clear the lamp. When the guards have very heavy strands, confining collars, or cast half-reflectors as a part of the guard, it is generally possible to accommodate the new mill-type lamps by using the same socket extensions suggested for use with the reflectors.

Already some of the manufacturers have produced guards and reflectors designed especially for the new lamps, while others will undoubtedly redesign their equipment where possible, to fit.

Textile Printing

Its Power Requirements and Electric Drive

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***Review of the Subject.**—Textile printing is the process of applying colored patterns and designs to all sorts of textile fabrics. The origin of the art dates back about 2000 years and credit for its discovery is given to both China and India. The present method of printing, known as cylinder or roller printing was invented and received its initial success about 1783-85.*

There are five methods used in textile printing, namely hand block printing, perritone or machine block printing, stenciling, flat surface printing from engraved copper plates, and cylinder printing from engraved copper rollers.

Of the five, cylinder printing is the most modern and important. By this means almost any style of design on almost any fabric can be produced in from one to sixteen colors, and the output from such a machine compared to hand block printing is enormous. For example, the cylinder machine can readily print in 1½ minutes the same number of yards of cloth that would require 15 hours by the block method.

The machine in its simplest form, viz.: a one-color machine, consists of a print roll or hollow copper cylinder upon which the pattern to be printed is engraved, a cast iron cylinder, the surface of which serves as a backing for the cloth to be printed, the furnisher or roll which carries the color to the print roll, the cleaning doctor which removes the surplus color from the print roll, and the color box which holds the color. The rolls are suitably mounted in bearings so that the print roll surface is in contact with the cylinder, the cloth passing between the print roll and the cylinder. Color is supplied from the color box by the furnisher to the print roll which imparts it to the cloth. After printing the cloth is passed over dryers to dry the fresh color.

The load on a printing machine consists of two parts, (a) constant load consisting of the dryers, guide roll and cloth conveyers, and (b) a variable load depending principally upon the class of goods to be printed, the length of and pressure used on the print rolls and the speed of the machine. The print roll pressure depends much upon the operator giving what in his estimation is the proper set for the rolls. This has been found to vary as much as 100 per cent for the same class of goods.

A series of tests made on several machines each driven by a d-c. motor, in one plant printing cotton cloth 27 to 36 in. wide, gives the following results:

Speed Variation: On machines ranging from four to nine colors a maximum machine speed range on any one machine was 4.82 to 1 with a maximum and minimum production for all machines of 84 to 1¼ yards per minute.

	POWER INPUT	Production
Machine	*Watts Input*	*Yd. per min.*
Duplex 2-color	*4950– 8800*	*14.5–43.5*
Single 5- "	*2200– 8800*	*22.0–82.0*
" 6- "	*3960– 7040*	*22.8–54.5*
" 8- "	*4620–11000*	*15.0–72.0*
" 9- "	*4620–12980*	*15.4–56.5*

From a variety of tests in different plants it appears that no fixed rule can be given to cover power requirements of a machine of given size. Experience and tests in a given plant enable one sometimes to fix approximate ratings for these machines, running a given line of goods. For example, a large printing plant running silk goods has adopted the following ratings.

Three-color machine	*10 h. p.*
Six " "	*15 h. p.*
Eight " "	*20 h. p.*
Twelve " "	*30 h. p.*

Another large printing plant running cotton goods has adopted the following:

Three-color machine	*20 h. p.*
Five " "	*27 h. p.*
Six " "	*35 h. p.*

There are three general methods of electric drive used on printing machines: (1) Direct-current motor with multi-voltage control. (2) Commutator-type a-c. motor. (3) Direct-current motor with field and armature control by resistance. The first is one which supplies a number of operating voltages for the motor to give the necessary speed changes and requires special generating equipment, together with additional lines to supply these voltages. The second is the straight series type commutating motor with brush-shifting device. The motor is operated from a constant-potential a-c. line and speed changes are obtained by shifting the brushes on the commutator.

The third is the standard d-c. type with speed control through resistance for both field and armature, and is operated automatically by push buttons or manually with face plate or drum controller.

The control for the d-c. motor consists of a series of magnetic contactors and rheostats either mounted complete on a panel or with rheostats combined in a single unit and separately mounted.

The operating push-button station usually has 5 buttons consisting of the "start," "stop," "jog" or "inching," "low speed," and "high speed." The jog or inching button is for the purpose of operating at low speed when setting the print rolls for correct registration. The start button is for automatically accelerating to the speed for which rheostats are set (this speed may be low or full-load speed of the motor, depending upon whether the slow or the fast button has been depressed), the slow button for the low speed to enable the operator to inspect the quality of printing, the fast button to bring the motor up to the highest speed at which the cloth can be printed and dried, and the stop button to stop the machine on any speed. Single stop buttons are in addition located at several convenient locations for stopping.

Dynamic braking is often desirable to bring the machine to a quick stop and is readily obtained with this control.

TEXTILE printing is the process of applying by various means colored patterns or designs to all sorts of textile fabrics, cotton, wool, silk, jute, linen and various mixtures of these and other fabrics.

The process is a form of dyeing and differs from it only in the fact that in dyeing the goods are colored uniformly throughout, while in printing, the color is placed on part of the goods only in the form of a design. The basic coloring material used for both is the same, although any colors capable of being made into a viscous fluid can be used for printing, in which case the development of the color may be completed either by steaming or dyeing.

History

Without attempting to go into the details of the history of the art, a few facts gleaned from authorities on the subject will give an idea of its origin and entrance into Europe where it received its greatest impetus and development.

The art of printing appears to have been discovered and practised independently and at different times by several countries. Letter press printing from engraved blocks of wood was practised in China nearly two thousand years ago. Printed cottons by the Hindoos were known and esteemed by the Romans in the early days of the empire and discoveries in the Egyptian tombs of fragments of cloth decorated with colored designs give evidence of a knowledge of some form of the art. The matter of priority seems to be an unsettled question, but it is generally conceded to lie between China and India. The Chinese were the first to use engraved blocks of wood for general printing and it is thought probable that the same idea would lead to the decoration of textiles. On the other hand, as the art was a flourishing commercial industry in India during the earliest centuries of the Christian era, it is possible that the art originated in this country. In any case, the source of European textile printing is traced to India.

About the latter part of the seventeenth century, the French, from their possessions in India, obtained a knowledge of the art and it is probable that they were the first to practise calico printing in Europe. From there it rapidly became known in Germany, Holland and England, and later spread to other countries. At the present time it is practised in all parts of the civilized world, and advance in the art in the last two centuries has been so great, and the output so large, as to be many times that of the eighteen centuries preceding.

The present method of printing, known as cylinder or roller printing, is the product of the invention generally credited to Belle, a Scotchman. Patents were taken out by him in 1783, and from 1785, when it received its initial success, to the present time, it has been the method most largely used.

Methods of Printing

There are five methods used in textile printing, viz., hand block printing, Perritone or machine block printing, stenciling, flat press printing from engraved copper plates, and cylinder printing from engraved copper rollers.

Of the five, cylinder printing is the most modern and most important.

Each method has its advantages and no one can replace the other without sacrificing some desirable quality of work. Block printing is the oldest and generally considered the most artistic and after cylinder printing, the most important. In block printing, the design is cut in relief in a block of close-grained wood, and the color is applied to the raised parts and the block is stamped by hand or by machine upon the cloth to be printed; while in cylinder printing, the design is engraved on a copper roller and the color is applied to the incisions and the impression made by pressing the color into the cloth by revolving the roll and pressing the cloth against its surface, both operations being done by the machine. By this means nearly any style of design on almost any fabric can be produced in from one to sixteen colors and the output from such a machine compared with hand block printing is enormous, running as high as 18,000 yards of cloth in one color and 9000 yards in twelve colors per machine in a working day.

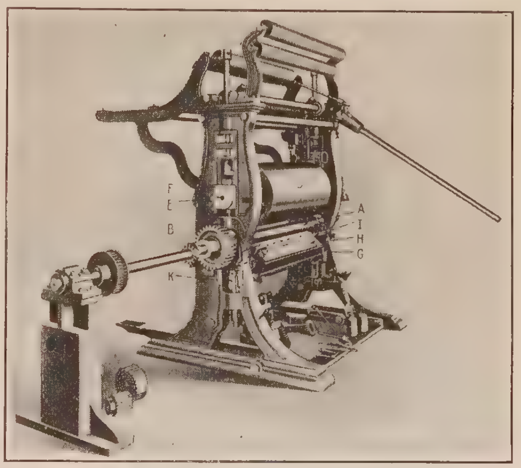

Fig. 1—One-Color Machine

A Print roll.
B Print roll mandrel.
C Impression cylinder.
E Cylinder shaft.
F Cylinder bearing box.
G Color box.
H Color furnisher roll.
I Cleaning doctor.
K Print roll pressure screw.

Courtesy Rice, Barton & Fales Machine & Iron Co., Worcester, Mass.

To quote an apt comparison given by Mr. Robert Roech, in a paper read before the National Association of Cotton Manufacturers:

> To state briefly, block printing was done on precisely the same principle as the stamp and pad in common use today, but on a larger scale. Blocks were usually ten to twelve inches square, so that with a block of 12 inches square it would require 450 impressions to print a piece 50 yards long and one yard wide, and if it should happen to be a four-color pattern it would then mean 1800 impressions. It would take a very smart printer to print two impression per minute, making allowance for changes, etc. This would mean 15 hours for 1800 impressions, whereas a cylinder printing machine could readily do the same number of yards in one and a half minutes. This gives an idea of the immense gain in product since the introduction of the cylinder printing machine, and for many classes of fine work the difference in quality is almost as marked.

Cylinder Printing Machine

The modern cylinder printing machine is illustrated in Figs. 1 and 2.

Fig. 1 shows a one-color machine, which, as the name

implies, prints the design in but one color and is therefore the simplest of this class of machines. Fig. 2 gives the end view of a two-color machine, and is here shown with Fig. 1 to illustrate more clearly the relation of the print roll to the cylinder. Referring to both figures, the machine consists of the following working parts:

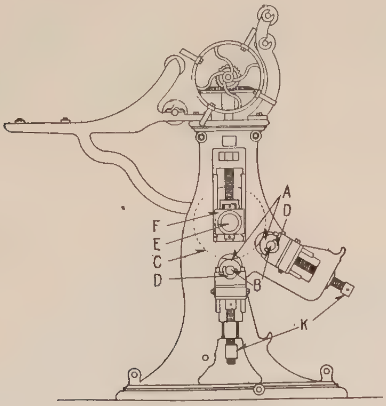

Fig. 2—Two-Color Machine

A Print rolls.
B Print roll mandrel.
C Impression cylinder.
D Mandrel bearings.
E Cylinder shaft.
F Cylinder bearing box.
K Print roll pressure screws.

Courtesy Rice, Barton & Fales Machine & Iron Co., Worcester, Mass.

Print roll *A*—this is a hollow copper cylinder engraved with the pattern to be printed and is mounted on a steel shaft *B*, called the mandrel, which has its bearings *D* at each end.

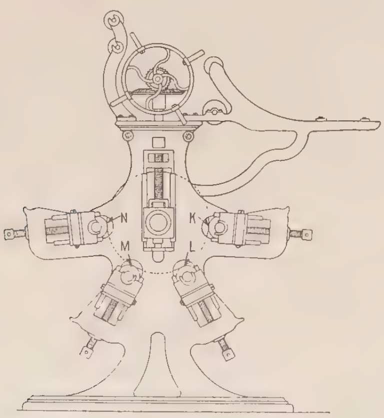

Fig. 3—Four-Color Machine

K, *L*, *M*, *N*, print rolls.

Courtesy Rice, Barton & Fales Machine & Iron Co., Worcester, Mass.

Cylinder *C*, a cast iron cylinder mounted on a steel shaft *E* which runs in adjustable bearing boxes *F* at each end. This cylinder furnishes the surface backing for the cloth to pass over while being printed and it is against this cloth on the cylinder that the print roll *A* is pressed by screws *K*.

Furnisher *H*. This is a wooden or brush roll, mounted on a shaft with bearings at each end, which runs partly immersed in the color contained in the color box *G* and operates within 1/16 in. of the print roll.

Cleaning doctor. This is a sharp-edged metal blade which rests upon and behind the print roll about midway between the contact with the cylinder and the furnisher. Its function is to scrape off the superfluous color from the smooth parts of the print roll, leaving only the color in the lines of the engraving.

Lint doctor. This is a small blade mounted on the opposite side of the roll from the cleaning doctor and its function is to catch the loose filaments and nap from the cloth which stick on the print rolls. It is used only where goods have a tendency to shed lint.

Lapping. In order to impart to the cylinder the elasticity necessary to obtain a full impression of the pattern, the cylinder is wrapped with several thicknesses of special fabric called lapping.

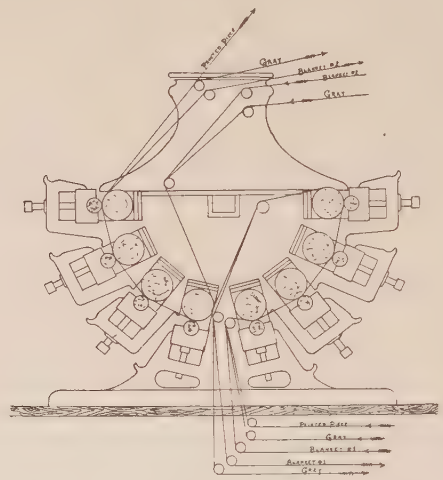

Fig. 4—Eight-Color Duplex Machine

Courtesy Rice, Barton & Fales Machine & Iron Co., Worcester, Mass.

Blanket. In order to give additional spring to the surface against which the print roll works, an endless woolen or rubber blanket circulates around the cylinder next to the lapping. See Figs. 4 and 5.

Back gray. This is a cloth which is run over the cylinder between the blanket and the cloth to be printed and its function is to absorb the color which comes through the printed cloth, thus preventing blurring of the printed cloth. See Figs. 4 and 5.

The above constitute the principal working elements of the machine. Other parts, such as the supporting frame, driving gears, cloth rolls, adjusting screws, etc., are contributory to revolving the print roll, furnishing the color therefor and passing the cloth over the cylinder to receive the printed design.

A two-color machine, Fig. 2, is made by adding to the one-color machine a second print roll with its color pan, furnisher and doctor. The surface of this second roll has engraved on it that part of the complete design which is to be printed in the second color, and the roll is so adjusted on the cylinder as to match and complete the counter part of the design printed from the

first roll. In like manner a four-color machine is made by assembling four print rolls K, L, M and N, as shown in Fig. 3. All other parts of the machine remain essentially the same, except that the supporting frame is made heavier and the necessary bearings and adjusting screws for the additional print rolls with their auxiliaries are added.

Setting the Machine

Before attempting to print even a sample of cloth, each of the print rolls of the machine is adjusted so as to give very nearly the correct registering of the design, one with the other. Two settings are necessary: First, longitudinally. This is accomplished by shifting each roll so that the index line of each cut around the circumference of the roll near the end is in the same vertical plane; this being determined by use of a small square placed on the surface and squaring successively each print roll from the cylinder. Second, circumferentially. This is accomplished by revolving each print

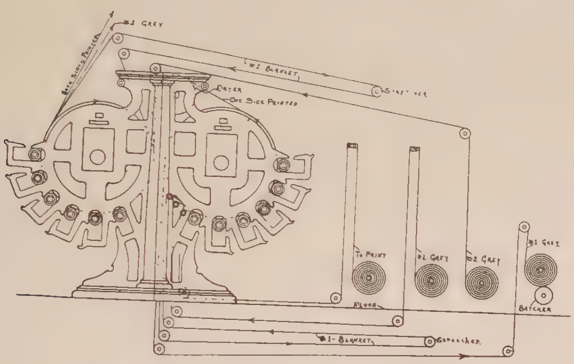

Fig. 5—Twelve-Color Double-Cylinder Duplex Machine
Courtesy Rice, Barton & Fales Machine & Iron Co., Worcester, Mass.

roll so that the index point (marked on the roll) comes into register on the cylinder; this being determined by the use of a tape placed around the cylinder and having distance marked on it equal to the circumference of each print roll.

After these adjustments are made, the index points are filled with color and a small piece of cloth stuck to the gray is run slowly through the machine. The registration is printed on this cloth and if not correct, further adjustments are made and the cloth run through again. This is repeated until the registration is nearly correct. After this a quantity of cloth is run through the machine at lowest speed during which the final adjustment for registration of the complete design is made.

Running the Machine

After setting the machine, the goods are then run through at full speed, which varies with the class of goods and the number of colors being printed, *e. g.*, on some cotton goods this may range from 40 to 80 yards per minute. As the cloth comes from the machine it is passed through hot air dryers, or over steam drying cans to dry the fresh colors, and this rate of drying determines in a measure the speed at which the cloth may be printed. Also inspection of the cloth requires a slowing down from full speed at intervals.

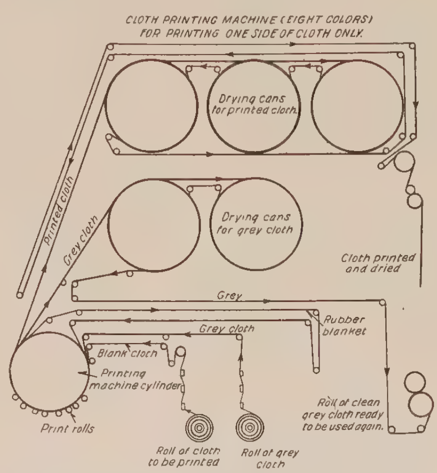

Fig. 6—Diagram Showing Travel of Print Cloth, Gray Cloth and Blanket during Printing and Drying Process
On a machine printing on one side only.

Load

The load of a printing machine unit is made up of two parts: (a) A constant load consisting of the dryers for the printed cloth, the delivery mechanism for the cloth, grays and blankets to and from the machine and dryers, the dryer blanket washer (if used) and oscillation of doctors. (b) A variable load depending on the following:

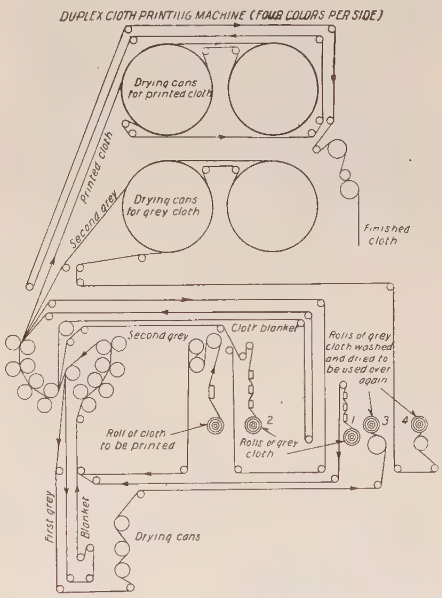

Fig. 7—Diagram Showing Travel of Print Cloth, Gray Cloth and Blanket during Printing and Drying Process
On a machine printing on both sides of the cloth or "duplex" machine.

1. Kind of goods being printed.
2. Length of, and pressure used on print rolls.
3. Speed of the machine.
4. Length of, and pressure used on color doctor.
5. Diameter of roll of cloth to be printed being fed to the machine and the weight applied to the brake wheel on the same.
6. Diameter of roll of grays and weight applied to the brake wheel on same.
7. Bearing friction of cylinder.

Items 4 to 7 inclusive may be considered negligible when compared with the total power requirements. Items 1, 2 and 3 are the important items to be considered, and of these, item 2 is most important. The pressure on the cylinder makes up the larger part of the load and while the amount of this pressure or set of the print rolls depends upon and should be determined by the class of goods being run, it is in many cases determined by the operator, and as operators differ in their ideas as to how much set gives the best results, this item is not easily estimated. It depends entirely upon the human element and has been found to vary 100 per cent on similar work. Apparently there is no rule for the amount of this set, nor any means used to indicate it. Where a machine is driven by an electric motor the amperes for a given speed would indicate very closely the relative set. A large ammeter then placed where the operator and foreman could easily read it would be a means of determining and always running with the right set for the same goods.

Following are a series of tests made on several sizes of machines, showing speed variations and loads under normal operating conditions. The tests were made with d-c. motors with hand control.

Tests

1. This series of five tests made on different machines shows the production and speed ranges during normal operation. It will be noted that the production ranged from 14.5 to 82 yards per minute, while the extreme speed range was 4.82 to 1.

Colors	Size roll	Driving shaft rev. per min.		Yd. per min.		Speed range
		Min.	Max.	Min.	Max.	
4	16–½	43	129	14.5	44.5	3.0 –1
5	16–¼	70	238	22.0	82.0	3.4 –1
6	15–⅞	68	211	22.8	76.0	3.1 –1
8	15	48	231	15.0	71.5	4.82–1
9	16–¾	49	173	15.4	56.5	3.5 –1

2. These tests made on one machine, running first seven colors, then eight, show extreme changes in speed sometimes called for.

Colors	Size roll	Driving shaft rev. per min.		Yd. per min.	
		Min.	Max.	Min.	Max.
7	15–⅞	24.5	220	8.1	72.6
7	16–¼	4.2	252	1.4	84.0
8	17–⅛	25.0	188	8.4	62–½

The following tests show speed and watts input on control points provided with electric drive on different sized machines on normal operation.

3. Test on two-color duplex machine, with two print rolls per side, two grays on one side and one on the other, Baker cloth blanket, three drying cans for cloth, two drying cans for one gray and three small drying cans for the other gray.

[illegible]trol points	Shaft rev. per min.	Yd. per min.	Motor rev. per min.	Watts input
1	43	14.5	69	4950
2	56	18.8	90	4620
3	63	21.1	101	3850
4	65	21.9	104	4950
5	83	28.1	133	5060
6	105	35.3	168	6160
7	115	39.4	184	8800
8	129	43.5	206	8800

4. Test on five-color machine with drag roll, 31-in. cotton cloth, two grays, baker cloth blanket, three cloth drying cans, two gray drying cans.

Control points	Shaft rev. per min.	Yd. per min.	Motor rev. per min.	Watts input
1	70	22	112	2200
2	75	25	120	2640
3	74	23.4	118	2530
4	83.5	28	133	3080
5	89	30	142	3080
6	116	40	185	3190
7	147	50	235	6380
8	147	50	235	6380
9	147	50	235	6380
10	168	60	269	6600
11	180	63	288	7700
12	238	82	381	8800

5. Test on six-color machine with drag roll printing 27-in. cotton cloth with one gray and rubber blanket.

Control points	Shaft rev. per min.	Yd. per min.	Motor rev. per min.	Watts input
1	68	22.8	109	3960
2	61.5	20.3	99	2860
3	68.5	23	110	2750
4	76.5	25	122	3190
5	88	29.5	141	3190
6	114	38.4	183	4180
7	133	44	213	5500
8	144	48.5	230	6160
9	141	47	226	6600
10	160	54.5	256	7040

6. Test on eight-color machine with one gray, rubber blanket, three cloth dry cans, 84 in. by 50 in., two dry cans for gray, and printing 27-in cotton cloth.

Control points	Shaft rev. per min.	Yd. per min.	Motor rev. per min.	Watts input
1	48	15	77	4620
2	58.5	18.3	94	4070
3	62	19.7	99	3850
4	65.5	20.5	105	4070
5	87	27	139	4290
6	109	33.9	175	4950
7	124.5	38.8	199	7920
8	139	43.3	222	7920
9	135	42	213	7920
10	160	50	256	7920
11	179	56	287	8800
12	231	72	370	11000

F. 7.—Test on nine-color machine with one gray, rubber blanket, cloth 36 in. wide.

Control points	Shaft rev. per min.	Yd. per min.	Motor rev. per min.	Watts input
1	49	15.4	80	4620
2	68	22.8	111	4950
3	65	20.7	106	4730
4	70.5	22.2	116	4950
5	85	27.1	139	5500
6	104.5	33.5	171	6710
7	130	42.2	213	10100
8	157	51.2	257	11000
9	144	47	236	11000
10	152	49	249	11000
11	173	56.5	283	12980

From the foregoing it may be seen that the load of a printing machine unit is determined by the operating conditions existing in each plant and that no rule can be given to cover it for cases in general. Experience and tests have enabled some plants to fix an approximate rating for the different sizes of machines running their particular line of goods, *e. g.*, a large plant printing silk goods has adopted the following ratings:

Three-color machine.............. 10 h. p.
Six-color machine.................. 15 h. p.
Eight-color machine............... 20 h. p.
Twelve-color machine............. 30 h. p.

Another large plant printing cotton goods adopted the following:

Three-color machine.............. 20 h. p.
Five-color machine................ 27 h. p.
Six-color machine.................. 35 h. p.

Another specified 50 h. p. for an eight-color machine on cotton goods.

Method of Driving

The print rolls which are the principal part of the machine are run by one large gear *A* (Fig. 8) separately mounted and meshing with the print roll pinions *B*. This gear is in turn driven by pinion *C* mounted on a separate shaft *D*. This is in turn driven by gear, chain or pulley driven from a general power line shaft, separate steam engine or electric motor.

Whenever electric power is available, the line shaft or steam engine methods of drive are usually superseded by the electric motor and control designed to give the required operating speeds.

On account of the wide range of various speeds required for setting, testing and running the cloth, also because of the necessity of frequently running goods at low speeds, and as the machine may run for a considerable time at low speeds during which the motor should be efficient, this is best obtained with a direct-current motor.

There are three systems of electric drive applicable to printing machines, all of which are designed to give the speed changes required for this class of work, viz.:

(1) Direct-current motor with multi-voltage control,
(2) Commutator-type a-c. motor,
(3) Direct-current motor with field and armature control by resistance.

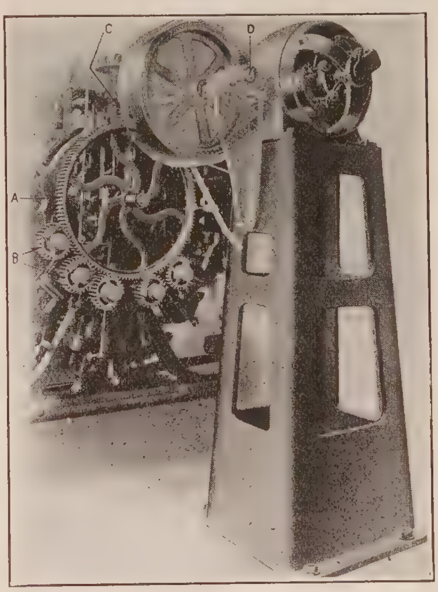

Fig. 8—Drive End of Printing Machine with Standard D-C. Motor and Chain Drive

A Main driving gear for print rolls.
B Print roll gears.
C Driving pinion.
D Driving shaft.

Courtesy Rice, Barton & Fales Machine & Iron Co., Worcester, Mass.

The first, or multi-voltage system is one which supplies a number of operating voltages for the motor to give the necessary speed changes. The system requires special generating equipment and also additional line wires to supply these voltages. Hand or automatic control is used to throw the motor on to the different lines.

The second, or commutator-type a-c. motor, is the straight series type commutating motor with brush shifting device, the motor being operated from the constant voltage a-c. lines, and the speed changes obtained by shifting the brushes on the commutator.

The third, or direct-current type with field and armature control by resistance, is the standard d-c. motor

used with external resistance for both field and armature, and manipulated automatically by push buttons or by hand with face plate or drum controller.

The standard direct-current motor has long been successfully applied to this class of work. It meets the requirements of speed changes and runs efficiently at light loads, a condition which often exists in printing.

The particular feature which has lately brought the standard d-c. motor to the fore for this application is the development of the automatic control for this motor. This enables the printer to give his entire attention to the product and to change quickly and adjust speeds from any selected locations.

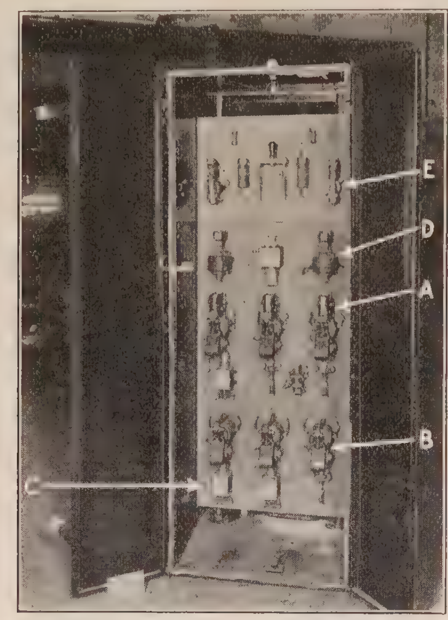

Fig. 9—Automatic Electric Control Panel for D-C. Motor for Printing Machine

A Shunt armature contactor.
B Armature accelerating contactor.
C Armature accelerating relays.
D High torque relay.
E Full field relay.

The Control

This control consists of a series of magnetic contactors and rheostats, either mounted complete on a panel or with rheostats combined in a single unit and separately mounted.

The speed of the motor is regulated through armature and field control by the use of these contactors and resistances and may be controlled by hand operation of the rheostats, or automatically by the use of push-button stations. The low operating speeds are obtained by the use of resistors, both in series and in shunt with the armature, the field of the motor being at its maximum strength. The higher speeds are obtained by first connecting the armature of the motor directly to the line and then weakening the field.

Assuming that the controller is manipulated by means of push buttons, five usually constitute a complete set. These consist of a "start," "stop," "jog" or "inching," "low-speed," and "high-speed" buttons.

The jog or inching button is for the purpose of operating at a low speed when setting the print rolls for correct registration. This would be a speed less than the rated low speed of the motor; *e. g.*, if the motor is designed to give 500 to 1500 rev. per min., by field control, the jog button should give a motor speed of 125 rev. per min. if held down long enough for the motor to attain this speed. In setting for registration, however, the button is frequently pushed and released before the motor attains this speed, so that mere starting of the print roll may be accomplished. The machine should run only while the button is held down, and stop when the button is released. This enables the printer to make a rapid setting and prevents waste of cloth.

After the setting of the print rolls, the machine is operated for the normal run from the four remaining buttons.

In starting the machine, the "start" button being depressed momentarily, causes the motor to accelerate automatically to the speed for which the rheostats are set. This speed may be a fraction of or the full speed of the motor depending upon whether the "slow" or the "fast" button is depressed. Either speed is predetermined for the class of goods to be run, the low speed being such as will enable the operator to inspect the quality of printing, which may be one-quarter to one-half the low rated speed of the motor, and the "fast" being the highest speed at which the cloth can be properly printed and dried. The motor continues to run at this speed until changed by depressing another button. If the machine is running full speed, then depressing the "slow" button reduces the speed to that usually required for inspecting, or if running at low speed, then depressing the "fast" button increases the speed to full. Depressing the "stop" button stops *the motor when running on any operating speed or during acceleration.*

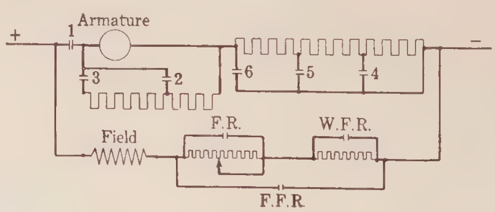

Fig. 10—Control Diagram for D-C. Motor for Printing Machine Drive

Usually several "stop" buttons are connected in series and located one at the front of the printing machine and one at the cloth delivering end of the dryer, and often between these points as may seem advisable so that the motor can be stopped from these points during ordinary inspection, or in case of accident.

A "safe run" button station is sometimes provided near the five-button station for making

the machine safe during repairs, adjustments, or changing the print rolls.

Dynamic braking is *often desirable* to bring the machine to a quick stop and can be readily obtained by connecting resistance across the armature cricuit of the motor when the line contactor is open.

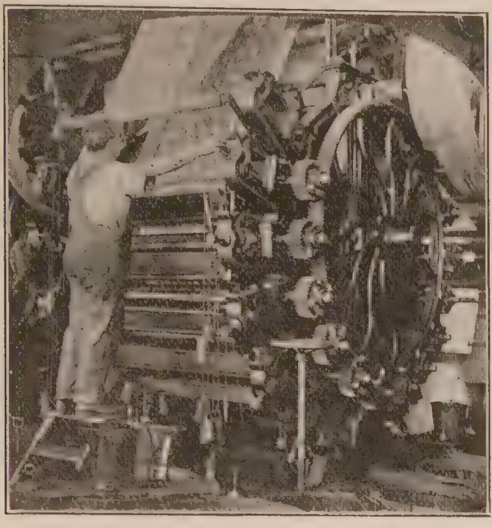

Fig. 11—Twelve-Color Cloth Printing Machine in Operation, Lawrence, Mass.

Tubs containing colors shown in lower foreground. Finished printed cloth shown above operator.

Courtesy National Geographic Society, Washington, D. C.

Fig. 10 illustrates the scheme of connection which shows the principal operating features of such a control. The starting resistor in the armature circuit of the motor is short-circuited by contactors No. 4, 5, and 6, the closing of these being controlled automatically by relays which function in proportion to the load on the motor. The other resistance in the armature circuit is used for regulating the speed of the motor and for dynamic braking. The resistor in series with the field winding is used for obtaining the higher operating speeds by reducing the field strength of the motor. This field rheostat is short-circuited by a relay which gradually reduces the field strength during acceleration by alternately opening and closing the shunt to this rheostat. This relay is actuated by a series winding which closes the contact when the current exceeds the fixed value and opens it when the current is reduced to normal.

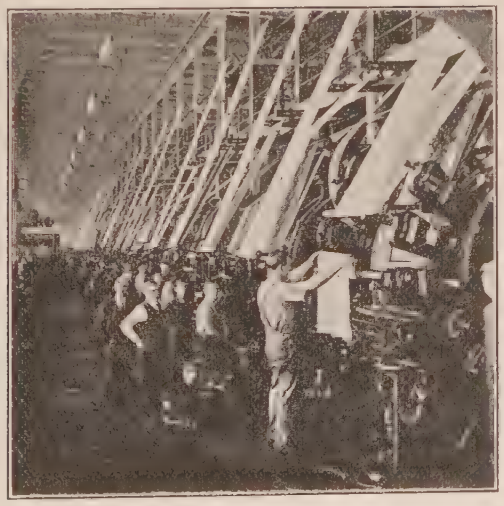

Fig. 12—Battery of 48 Printing Machines at Work, Lawrence, Mass.

Courtesy National Geographic Society, Washington, D. C.

High starting torque is very desirable in such an application and can be readily obtained by the use of a torque relay.

It is very desirable to have the current in the shunt field reduced below normal while the motor is not running, to prevent heating of the field coils. At the same time normal field current is preferable for dynamic braking. Both can be obtained by the use of a relay.

This paper has been prepared with the assistance of H. D. James, member of the committee on Industrial and Domestic Power.

EFFECTS OF DISTRIBUTED CAPACITY BETWEEN INDUCTANCE COILS AND GROUND

An inductance coil behaves in an electric circuit primarily as an inductance. The potentials of the different parts of the coil are, however, different from each other and from the potential of the ground. For this reason the coil also behaves to a certain extent as an electric condenser. The effective capacity of an inductance coil depends in general both on the capacities existing between parts of the coil itself, and between parts of the coil and the ground.

On account of the importance in radio communication of capacity effects in inductance coils, careful studies of these effects, have been made at the Bureau of Standards. An interesting result which has been found is that one effect seems to depend primarily on the capacity of the coil to ground. This effect is observed when two condensers in series are connected across the terminals of the inductance coil, and the common terminal of the two condensers is grounded. If the inductance coil possesses capacity to ground, the familiar criterion for resonance in the system, computed from the known values of the capacities of the two condensers, will not obtain.

If the method of measuring the effective capacity is that of resonance adjustment, and if a coil symmetrical as to its two terminals is used, it is found that with the common terminal grounded the capacity of the two condensers in series determined as the product of their capacities divided by their sum, is linearly related to the reciprocal of the sum of their capacities. This relation has been verified both mathematically and experimentally.

The results of this investigation are given in a recent publication of the Bureau, Scientific Paper No. 427, by Gregory Breight.

Resistance Neutralization

An Application of Thermionic Amplifier Circuits

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Review of the Subject.—*A power amplifier may be so connected to the circuit supplying the power to be amplified that it introduces terms into the equation for the current in the power circuit which subtract from the resistance terms. Upon this fact depends the operation of the device as a generator of sustained oscillations, as a regenerative amplifier, and as a resistance neutralizer. In the treatment of oscillating audion or triode circuits this fact has been pointed out by a number of writers but the more general significance of these subtractive terms has never been discussed. This paper points out that, by making use of the idea of resistance neutralization, circuits and systems having all the properties of low-resistance systems and also a number of other unique properties may be obtained.*

The first part of the paper derives and discusses the current and power relations which obtain in circuits having a resistance neutralizer associated with them. One of the things brought out is that not only does the neutralizer supply power to the circuit but it also causes the generator or source of driving e.m. f. to furnish more power to the circuit than it would were the neutralizer not present. Thus if the source of driving e. m. f. is the impinging of electromagnetic waves upon a wireless antenna the neutralizer not only amplifies the power received but it actually causes the impinging waves of the correspondent station to give up more power to the antenna circuit while it causes the waves from detuned station to give up less power to the receiving circuit.

The power relations cited above while important are not the most important results obtained by resistance neutralization. At resonance, the power delivered to a wireless receiving system by impinging waves is inversely proportional to the net resistance, while the power received from detuned stations is practically independent of the net resistance. The neutralizer, by lowering the net resistance of the receiving system, thus causes the ratio of signal to interferent power to increase. In a simple series antenna circuit the ratio of signal to interferent power, where the interferent source may be either atmospheric strays or interferent station, is a function of $(L/R)^n$ where n is a positive number. The neutralizer thus increases the selectivity of the receiving station against all types of disturbances.

A general physical argument is given (paragraph 7) to show that a triode may be made to function as a resistance neutralizer. This physical argument is illustrated by a mathematical treatment of the steady and transient states for a particular method of associating the triode with the circuit in which neutralization is desired. This mathematical treatment shows that under all conditions both in the steady and transient state, the neutralizer circuit functions so as to reduce the net resistance of the circuit of interest to some predetermined value. A numerical example is given to illustrate the mathematical theory. In this particular circuit the ratio of the signal to interferent power in the steady state is increased 200 fold by the insertion of the neutralizer.

Section (II) of the paper treats of the optimum conditions obtaining in receiving circuits containing a resistance neutralizer, and gives relations for the designing of an antenna and its circuits so as to obtain the maximum selectivity and maximum power abstraction from impinging waves. The last topic discussed (Section 12) deals with a circuit which neutralizes resistance for a narrow range of frequencies near a desired frequency and introduces resistance and reactance into the circuit for frequencies removed fom this band of frequencies. A numerical example is given to illustrate the theory. The performance curves of the neutralizer are given by Figs. 12 and 13. Fig. 14 shows the ratio of the power received at resonance to the power received from a detuned station by a given antenna circuit; first, without a neutralizer, second, with a pure resistance neutralizer, and third, with a selective neutralizer. For example, if the interferent source is detuned by 3 per cent the circuit without the neutralizer gives practically 1 for the ratio of signal to interferent power; with pure resistance neutralization the ratio is about 1300; with the selective neutralizer the ratio is increased to 3000.

CONTENTS

GENERAL THEORY OF RESISTANCE NEUTRALIZATION

1. *Purpose.* A power amplifier is a device having three elements so related that the supply of power to the *control* element of the device from an external system controls the delivery of a much larger amount of power from a *local source* of power to the third element, the *power receiving* element.

A power amplifier always comprises the three elements,

1. The control, or trigger, or power input element.

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2. The local source of power.
3. The power receiving, or power output element.

By suitable connections between the elements, the power available in the output element may be utilized in the following ways:

A. The power output may all be expended in the output element to accomplish some desired purpose: this is the case of *simple amplification.*

B. A part of the power output may be diverted to the control element to supplement the power received from the external or original actuating agency in such a manner as to increase the power amplifying ratio: this is the case of *regenerative amplification.*

C. A portion of the power output may be diverted to the external system which supplies the power to the control element in such a manner as to cause the driving forces in the external system to deliver more power to the external system. The amplifier thus supplies a part only of the increased power which is expended in the external system. In the mathematical treatment of the system the amplifier constants enter the equations of the external circuit in the form of terms which *subtract* from the frictional or resistance terms. The amplifier when thus associated with the external agency is therefore said to have the properties of a *negative resistance*: this is the case of *resistance neutralization.*

D. The power may be so diverted to the external system that any disturbance which is set up in the system may result in sustained oscillations (reciprocating motion) in a system in which the only driving force is the continuous force of the power source of the amplifier: this is the case of the *generation of sustained oscillations.*

The trielectrode thermionic amplifier (the audion or triode) has been used in radio telegraphy essentially as an amplifier and as a generator of sustained oscillations (the uses of the "triode" as a translator by rectification from radio to audio frequencies, and as a controller or modulator, are not under discussion) and its applications and possibilities as a *resistance neutralizer* seem to have been overlooked.[1] By this we do not mean to say that it has not been known that the amplifier constants enter into the dissipative terms as negative quantities. We mean that the possibilities of the use of the amplifier in such a manner as to increase the abstracting factor of a radio antenna for power from the correspondent station, and to increase the selective coefficient of an antenna against interferent sources are not generally known.

The present paper has for its object a detailed and quantitative treatment of resistance neutralization with special reference to its applications in increasing the selective properties of radio receiving circuits.

The treatment is divided into three general parts. In the first part, the general theory of resistance neutralization is developed. In this theory the conditions which a device must fulfill in order to function as a resistance neutralizer toward a circuit with which it is associated are arrived at. The second part shows how triode circuits may be designed to fulfill the conditions developed in the general theory, and thus how these circuits may be made to function as resistance neutralizers. The third part treats of the effects of resistance neutralization upon the abstractive and selective properties of radio receiving circuits.

2. *The Conditions Necessary for Resistance Neutralization.* Consider the circuit shown in Fig. 1. Let B represent a device feeding power into the circuit. B may have any voltage characteristic whatsoever. Let A be a device which introduces into the circuit

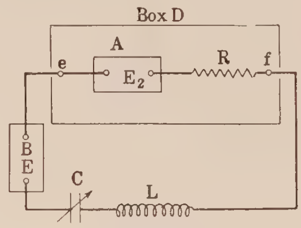

FIG. 1

1 an electromotive force e_2 which at every instant is directly proportional to and in the same direction as the current i in the circuit ($e_2 = N\,i$). The effect of the device A will be called *pure resistance neutralization.* This effect is termed pure resistance neutralization because if we were to inclose the resistance R and the device A in a box D and were to bring out two terminals, e and f, the box would act in all respects like a resistance of magnitude $R - N$.

The proof of this proposition is very simple. It consists in comparing the differential equation of the circuit of Fig. 1 with the differential equation of the same circuit if A were not present. Let the electromotive force of the source B be represented by e and that of the device A be expressed by the equation:

$$e_2 = N\,i \tag{1}$$

Kirchoff's law applied to the circuit of Fig. 1 gives the equation,

$$e - L\frac{d\,i}{d\,t} - R\,i + N\,i - \frac{q}{C} = 0 \tag{2}$$

Differentiating (2) with respect to time gives

$$\frac{d\,e}{d\,t} - L\frac{d^2\,i}{d\,t^2} - (R - N)\frac{d\,i}{d\,t} - \frac{i}{C} = 0 \tag{3}$$

If A were not present (3) would be

$$\frac{d\,e}{d\,t} - L\frac{d^2\,i}{d\,t^2} - R\frac{d\,i}{d\,t} - \frac{i}{C} = 0 \tag{4}$$

1. Since the above was written, we have found the circuit of Fig. 11 described by Armstrong and Pupin in a French Patent abstracted in the *Revue Generale de L'Ectricite*, Volume 5, page 270. This review of the patent, however, contained no analytic treatment of the circuit.

Equation (3) is sufficient to portray the relations in the circuit of Fig. 1 under all conditions and equation (4) is sufficient to portray the relations in this same circuit with A not present. The only difference between these equations is that (3) contains $R - N$ where (4) contains R. Therefore under all conditions and for all types of applied voltages the box D of Fig. 1 acts as a resistance of magnitude $R - N$.

3. *Power Relations.* In the circuit of Fig. 1 let the device B represent an alternator delivering a sine electromotive force whose root-mean-square value is E. Let X represent the net reactance of the circuit.

$$X = \omega L - \frac{1}{\omega C}$$

Then in the steady state, the current flowing in the circuit is,

$$\left.\begin{aligned} I &= \frac{E}{(R - N) + j\left(\omega L - \frac{1}{\omega C}\right)} \\ &= \frac{E}{(R - N) + j X} \\ I &= \frac{E}{\sqrt{(R - N)^2 + X^2}} \end{aligned}\right\} \quad (5)$$

The power P_B delivered by the alternator B is,

$$P_B = \frac{(R - N)\, E^2}{(R - N)^2 + X^2} \quad (6)$$

The power P_A delivered by the amplifier or resistance neutralizer A is,

$$P_A = \frac{N E^2}{(R - N)^2 + X^2} \quad (7)$$

The total power P_T delivered by both A and B is,

$$P_T = \frac{R E^2}{(R - N)^2 + X^2} \quad (8)$$

The power P_0 delivered by the generator B with the amplifier A removed is,

$$P_0 = \frac{R E^2}{R^2 + X^2} \quad (9)$$

Let the ratio

$$\frac{R - N}{R} \text{ be represented by } \gamma \quad (10)$$

This ratio γ may be called the *reduction factor* of the neutralizer when associated with the particular circuit. It is the factor by which the original circuit resistance must be multiplied in order to obtain the reduced or net resistance.

The ratios of the power delivered by the neutralizer to the power delivered by the alternator, etc. are as follows:

$$P_A/P_B = \frac{N}{R - N} = \frac{1}{\gamma} - 1 \quad (11)$$

$$P_T/P_B = \frac{R}{R - N} = 1/\gamma \quad (12)$$

$$P_B/P_0 = \frac{R - N}{R} \cdot \frac{R^2 + X^2}{(R - N)^2 + X^2} \quad (13)$$

$$P_A/P_0 = \frac{N}{R} \cdot \frac{R^2 + X^2}{(R - N)^2 + X^2} \quad (14)$$

$$P_T/P_0 = \frac{R^2 + X^2}{(R - N)^2 + X^2} \quad (15)$$

For the case in which the circuit is resonant to the frequency of the alternator B, the power ratios reduce to the following forms. These ratios also apply to the direct current case:

$$P_A/P_B = \frac{N}{R - N} = \frac{1}{\gamma} - 1 \quad (11a)$$

$$P_T/P_B = \frac{R}{R - N} = 1/\gamma \quad (12a)$$

$$P_B/P_0 = \frac{R}{R - N} = 1/\gamma \quad (13a)$$

$$P_A/P_0 = \frac{R}{R - N} \cdot \frac{N}{R - N} = (1/\gamma)^2 - 1/\gamma \quad (14a)$$

$$P_T/P_0 = \frac{R^2}{(R - N)^2} = (1/\gamma)^2 \quad (15a)$$

An inspection of equations (13) and (13a) shows that if the circuit is resonant, the presence of the neutralizer

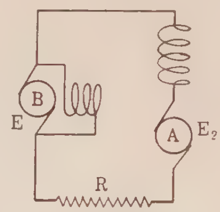

FIG. 2

in the circuit causes the alternator to deliver more power in the ratio of R to $(R - N)$, while if the circuit is so much out of tune that the resistance R is small in comparison with the reactance X, the presence of the neutralizer causes the alternator to deliver less power in the ratio of $(R - N)$ to R.

4. *A Simple Example of Resistance Neutralization.* As a simple example of resistance neutralization, consider the circuit shown in Fig. 2. In this circuit B is a shunt generator and A is a series generator used as a booster. For a limited range of current, the voltage of the booster A is approximately proportional to the current in the circuit. Within this range the following relations hold good:

$$E_2 = N I \qquad I = \frac{E}{R - N}$$

and the series generator acts as a resistance neutralizer.

5. *Departures from Pure Resistance Neutralization.* The conditions necessary for pure resistance neutralization may be summed up as follows:

1. The resistance neutralizer A must introduce into the circuit 1 an electromotive force in series with the electromotive force of the power supplying device.

2. The electromotive force introduced by the resistance neutralizer must at every instant of time be directly proportional to and in the same direction as the current in the circuit. $e_2 = N\,i\,; N > 0$

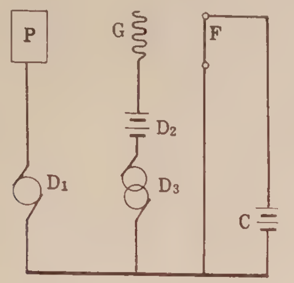

Fig. 3

Condition 2 insures that the following relations are obtained:

a. The voltage of A is in phase with the current i.

b. The voltage of A is of the same wave form as the current i.

c. The voltage of A is of the same frequency as the current i.

Small departures from these relations lead to small departures from the condition of pure resistance neutralization. For instance, a slight departure from the relation (a) leads to the introduction into the circuit equations of terms which add to or subtract from the reactance terms of the impedance, as well as the term which subtracts from the resistance. Thus a slight departure from relation (a) would cause the box D of Fig. 1 to act as a resistance of magnitude $(R - N)$ in series with an inductance or capacity. If the circuit were resonant to the frequency of the driving force and if the voltage of A departs from the relation

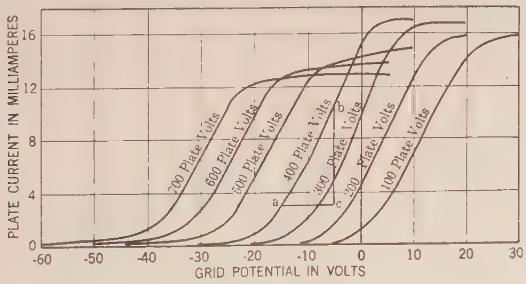

Fig. 4

(a), the circuit would no longer be in tune with the voltage of B. In most cases this can be taken care of by retuning or by tuning while A is included in the circuit.

II. The Three-Element Thermionic Amplifier or Triode Circuits as Resistance Neutralizers

6. *Definition of Triode Constants, Conventions and Notation.* Before commencing the discussion of the three-element thermionic circuit as a resistance neutralizer, it will be necessary to define the triode constants and to set forth the conventions which will be used in the following discussion.

The elements of the thermionic amplifier or triode are a heated cathode, F, an anode or plate, P, and a third electrode or grid G, interposed between the

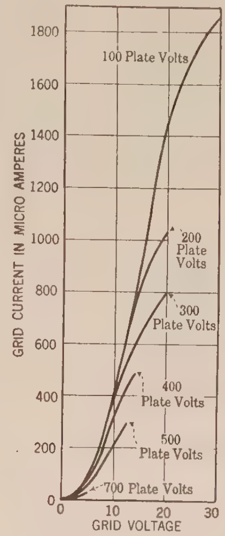

Fig. 5

cathode and anode. (See Fig. 3). In the circuits dealt with in this paper, these three elements are always connected through auxiliary apparatus to a common point or *bus*. Therefore all circuits will be represented in a manner similar to the circuit shown in Fig. 3.

The positive directions in both plate and grid circuits will always be so taken that a + e. m. f. in these circuits is an e. m. f. tending to cause current to flow *through the gas* from plate or grid to filament,—or tending to cause electrons to pass from filament to plate or grid.

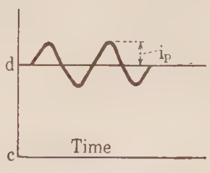

Fig. 6

By the *plate current* is meant the current flowing *from* the plate *through the gas* to filament and grid.

By the grid current is meant the current flowing *from* the grid *through the gas* to filament and plate.

By the *plate and grid potentials* is signified their potentials relative to the negative end of the filament.

Let the characteristics of the amplifier represented in Fig. 3 be given by the curves of Figs. 4 and 5. Let the voltages of the battery D_1 and the generator D_2 be so adjusted that conditions are represented by the

point o in Fig. 4. That is, the generator D_2 gives a voltage of 400 volts and D_1 a voltage of 10 volts. There is a continuous current of 6.45 milli-amperes flowing in the plate circuit. Now suppose the alternator D_3 is excited to give a voltage whose peak value is 5 volts. Operation now takes place over the 400 volt characteristic from a to b. The current in the plate circuit is shown in Fig. 6. This current can be broken up into a steady current of magnitude $c\,d$ and an alternating current of amplitude i_p.

Let the ratio of the plate alternating current to the grid alternating potential (the plate potential being kept constant) be called the controlled conductance of the plate *by the grid*, or briefly the *controlled plate conductance*, G_{cp}

$$\frac{\Delta I_p}{\Delta E_g} \text{ is represented by } G_{cp}$$

Let the ratio of the grid alternating current to the grid alternating potential (the plate potential being kept constant) be called the *grid conductance*, G_g.

$$\frac{\Delta I_g}{\Delta E_g} \text{ is represented by } G_g$$

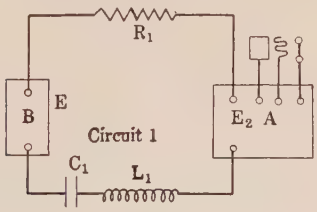

Fig. 7

Now imagine the alternator D_3 shifted to the plate circuit and from similar considerations let the following definitions be adopted:

Let the ratio of the grid alternating current to the plate alternating potential (the grid potential being kept constant) be called the *controlled conductance of the grid* by the plate, or briefly, the *controlled grid conductance*, G_{cg}

$$\frac{\Delta I_g}{\Delta E_p} \text{ is represented by } G_{cg}$$

Let the ratio of the plate alternating current to the plate alternating potential (the grid potential being kept constant) be called the *plate conductance*, G_p.

$$\frac{\Delta I_p}{\Delta E_p} \text{ is represented by } G_p$$

7. *Conditions Leading to Resistance Neutralization by Triode Circuits.* In Fig. 7 let A be a region in which circuit 1 is associated with the three elements of a thermionic amplifier. Let the association represented by Fig. 7 be such that the following conditions are fulfilled:

1. The grid must be excited from the circuit 1.
2. The amplifier must feed power into circuit 1, and the power fed into circuit 1 by the amplifier must be less than the sum of all the losses occurring in circuit 1.

In order to fulfill condition 2 the bulb must operate so as to transform d-c. power into a-c. power. This requires that

(a) The alternating voltages introduced into the plate and grid circuits using the bus as a reference shall be 180 deg. out of phase. Variations from a phase displacement of 180 deg. so long as these displacements do not exceed 90 deg. may obtain without causing the triode to cease to act as a generator. However, the closer these voltages approach to phase opposition, the closer the triode functions as a pure resistance neutralizer.

(b) The ratio of the plate alternating voltage to the grid alternating voltage must be less than the voltage amplification constant of the tube.

$$(e_p/e_g \text{ must be less than } G_{cp}/G_p)$$

Condition 1 above, taken together with requirements (a) and (b), insures that the fundamental of the voltage introduced by the triode into circuit 1 shall be of the same frequency as the current in circuit 1. If operation takes place about a correct point of the characteristic curve of the triode, and if the triode is not pushed too much for output, the harmonics of the voltage wave which it introduces into circuit 1 should be relatively small.

Condition 2, taken together with the considerations just mentioned, insures that the voltage introduced into circuit 1 by the triode will have a component in phase with and proportional to the current in circuit 1. Since the voltage e_2 introduced into circuit 1 by the bulb is of the same frequency as the current in circuit 1, it follows that the most general effect which this voltage can have upon the current in the circuit is to change its magnitude and phase position. Then, that the triode may deliver power to 1, the voltage e_2 must have a component in phase with i_1. Since i_1 and e_2 are practically sine waves, the only manner in which the component of e_2 in phase with i_1 can differ from i_1 is by a constant multiplier N. The amplifier thus reduces the effective resistance of the circuit from R_1 to $R_1 - N$.

The component of e_2 at right angles to i_1 introduces a reactance into circuit 1. By a proper choice of circuits and circuit constants, this reactance can be made large or very small at will. The amplifier thus may be used to neutralize or to add to the reactance of circuit 1. If circuit 1 is a tuned circuit, the reactance introduced by the amplifier can, in most cases, be taken care of by tuning while the amplifier is associated with the circuit.

If condition 2 is reversed, the bulb abstracts power from 1. The bulb may be made to function as a true positive resistance of value N.

8. *Derivation of the Steady State Equations for Fig. 8.* As an illustration of a specific triode circuit satisfying the conditions outlined above, the equations

for the steady state current in the circuit of Fig. 8 will now be derived and discussed. In Fig. 8, B represents an alternator generating a sine electromotive force. The capacities of the condensers C_3 and C_2 are assumed to be so large that the alternating currents which flow through these condensers cause no appreciable variation in the voltage across these condensers. The power circuit containing the alternator (circuit 1) is magnetically coupled in opposite directions with the plate and grid circuits (as illustrated in the figure). That is, if M_p is a positive quantity, M_g is a negative quantity, or vice versa. In the following equations M_p and M_g represent the algebraic values and not the absolute values of the mutual inductances.

Applying Kirchhoff's law to circuit 1, we obtain

$$E - R_1 I_1 - j\,\omega L_1 I_1 + \frac{j I_1}{\omega C_1} - j\,\omega M_p I_p - j\,\omega M_g I_g = 0 \qquad (24)$$

The last term may be made negligibly small and will therefore be dropped from this equation.

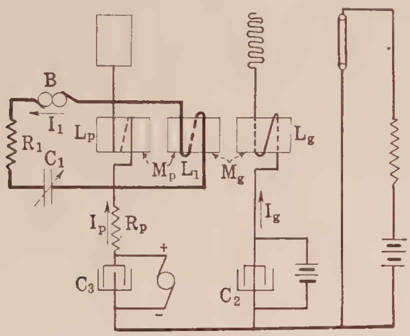

FIG. 8

The plate voltage is,

$$E_p = -j\,(\omega M_p I_1 + \omega L_p I_p) - R_p I_p \qquad (25)$$

The grid voltage is,

$$E_g = -j\,\omega M_g I_1 - j\,\omega L_g I_g - R_g I_g \qquad (26)$$

The last two terms are negligibly small and will be dropped. The plate current is,

$$I_p = E_g G_{cp} + E_p G_p$$

$$I_p = j\,\omega\,[-M_g I_1 G_{cp} - (M_p I_1 + L_p I_p)\,G_p] - R_p I_p G_p \qquad (27)$$

$$I_p = \frac{j\,\omega\,(-M_g G_{cp} - M_p G_p)\,I_1}{1 + R_p G_p + j\,\omega L_p G_p} \qquad (28)$$

Letting D represent $1 + R_p G_p$ (29)

and X_1 represent $\omega L_1 - \dfrac{1}{\omega C_1}$

and substituting the value of I_p from (28) in (24), there results,

$$E - R_1 I_1 - j X_1 I_1 + \frac{\omega^2 M_p (-M_g G_{cp} - M_p G_p)\,I_1}{D + j\,\omega L_p G_p} = 0 \qquad (30)$$

Writing h for $M_p(-M_g G_{cp} - M_p G_p)$ (31)

and solving for I_1, we obtain,

$$I_1 = \frac{E}{\left[R_1 - \dfrac{\omega^2 h D}{D^2 + \omega^2 L_p^2 G_p^2}\right] + j\left[X_1 + \dfrac{\omega^3 L_p G_p h}{D^2 + \omega^2 L_p^2 G_p^2}\right]} \qquad (32)$$

Equation (32) shows that the triode lowers the effective resistance of the circuit 1 by the amount

$$\frac{\omega^2 h D}{D^2 + \omega^2 L_p^2 G_p^2}.$$

The algebraic value of this quantity depends upon and is the same as the algebraic value of h. An inspection of the expression for h, equation (31), shows that the only conditions under which h is positive (or under which the triode acts as a resistance neutralizer)are that M_p and M_g shall be of opposite signs and $M_g G_{cp}$ greater than $M_p G_p$. If both of these conditions are not fulfilled the triode circuit increases the effective resistance of the power circuit.

The triode circuit also increases the effective inductive reactance by an amount

$$\frac{\omega^3 L_p G_p h}{D^2 + \omega^2 L_p^2 G_p^2}$$

This latter term can be made large or small at will. Thus the triode circuit may also be used to neutralize reactance or to introduce reactance into a circuit.

In order to see how closely the triode can be made to function as a true resistance neutralizer, it is necessary to obtain some idea of the relative magnitude of the terms involved in equation (32). In a particular radio antenna using ordinary laboratory inductances and a 100 watt audion bulb, the circuit constants had the following values:

$R_1 = 80$ ohms
$G_p = 200 \times 10^{-6}$ mhos
$G_{cp} = 3000 \times 10^{-6}$ mhos
$R_p = 5.13$ ohms
$L_p = 3350 \times 10^{-6}$ henrys
$L_g = 172 \times 10^{-6}$ henrys
$L_1 = 20320 \times 10^{-6}$ henrys
$M_p = 3000 \times 10^{-6}$ henrys
$M_g = 432 \times 10^{-6}$ henrys
$C_1 = 1.4 \times 10^{-9}$ farads (antenna)
$\omega_r = 1.875 \times 10^5$ rad/sec.
$R_g = 1.16$ ohms
$\omega_r^2 = 3.515 \times 10^{10}$

For this circuit, $D = 1.00102$, $\omega^2 L_p^2 G_p^2 = 0.0158$. $(D^2 + \omega^2 L_p^2 G_p^2)$ may for most purposes be written equal to unity. This will be done in the following equations:

$$h = 2.1 \times 10^{-9}$$
$$\omega^2 h = 74 \text{ ohms}$$
$$\omega^3 L_p G_p h = 9.23 \text{ ohms}$$

Now $\omega^3 L_p C_p h$ is the net reactance introduced by the neutralizer into the circuit 1. This term can be kept low if desired. If circuit 1 is a tuned circuit, the net reactance can in most cases be made zero by tuning while the neutralizer is associated with the circuit.

Calling $D = 1$, and neglecting $(\omega^2 L_p^2 G_p^2)$ in comparison with unity, equation (32) reduces to the simple form,

$$I_1 = \frac{E}{(R_1 - \omega^2 h) + j (X_1 + \omega^3 L_p G_p h)} \tag{33}$$

The power delivered by alternator B to the circuit 1 is,

$$P_B = \frac{E^2 (R_1 - \omega^2 h)}{(R_1 - \omega^2 h)^2 + (X_1 + \omega^3 L_p G_p h)} \tag{34}$$

If the net reactance is zero this becomes,

$$P_B = \frac{E^2}{R_1 - \omega^2 h} \tag{35}$$

9. *Complete Equations for Fig. 8.* If the triode circuit is designed to keep the reactive term low, a very close complete solution of the differential equations of the system is given by the following equations:

The current in the circuit 1 is,

$$i_1 = \frac{E}{\sqrt{(R_1 - \omega^2 h)^2 + X_n^2}} \cos(\omega t - \tau - \lambda) + [I_d \cos \beta t + (C_1 \beta E_{cd} + a/\beta I_d) \sin \beta t]\, \epsilon^{-\frac{R_1 - \beta^2 h}{2 L_1} t} \tag{36}$$

The counter electromotive force of the condenser C_1 is

$$e_c = \frac{E}{\omega C_1 \sqrt{(R_1 - \omega^2 h)^2 + X_n^2}} \cos(\omega t + \pi/2 - \tau - \lambda) + \left[E_{cd} \cos \beta t - \left(\frac{E_{cd}\, a}{\beta} + \frac{I_d}{C_1 \beta} \right) \sin \beta t \right] \epsilon^{-\frac{R_1 - \beta^2 h}{2 L_1} t} \tag{37}$$

In these equations the symbols have the following meaning: The alternating voltage impressed in circuit 1 is expressed by the equation $e = E \cos(\omega t - \tau)$. In which time is measured from the instant of switching in the voltage.

τ is the interval in radians from the moment of switching to the first positive peak of the impressed e. m. f.

λ is the angle of lag of the permanent current behind the impressed e. m. f. $= \tan^{-1} \dfrac{X_n}{R_1 - \omega^2 h}$

X_n is the net reactance $= \omega L_1 - \dfrac{1}{\omega C_1} + \omega^3 L_p G_p h$

$$I_d = I_0 - E/Z \cos(\tau + \lambda)$$

$$E_{cd} = E_{c0} - \frac{E X_c}{Z} \cos(\tau + \lambda - \pi/2)$$

Z is the net impedance $= \sqrt{(R_1 - \omega^2 h)^2 + X_n^2}$

$$X_c = \frac{1}{\omega C_1}$$

$$\Omega_r = \frac{1}{\sqrt{L_1 C_1}}$$

$$\beta = \Omega_r \sqrt{\frac{D L_1}{D L_1 + R_1 L_p G_p}}$$

$$a = -\frac{R_1 - \beta^2 h}{2 L_1}$$

These equations are identical in form with the equations for the start of an alternating current in the circuit with the neutralizer omitted. The only difference is that for the circuit without the neutralizer, R must be substituted for $R_1 - \omega^2 h$ and $R_1 - \beta^2 h$, X_1 substituted for X_n, and $\dfrac{1}{\beta L_1}$ written for $C_1 \beta$. This latter substitution is legitimate if β differs little from Ω_r.

III. Some Applications of Resistance Neutralization to Radio Receiving Circuits

10. *Increased Selectivity through Pure Resistance Neutralization.* One of the most important applications of resistance neutralization is in increasing the selective properties of radio receiving circuits. It is this application which will now be taken up.

In discussing the selective properties of radio receiving circuits, it is helpful to define some coefficients, the values of which for any circuit are a measure of the selectivity of the circuit. The steady-state selective coefficient, S_c, of a receiving circuit against a specified detuned frequency has been defined[2] as the ratio of the power delivered to the detector by waves of a frequency such as to make the circuit resonant and the power delivered to the same detector by waves of the same intensity but of the specified detuned frequency, the power being determined after the current builds up to the steady state value.

For the simple series circuit shown in Fig. 8, let E be the voltage induced by the impinging waves. The current in the circuit is

$$I = E/Z$$

and the power delivered to the detector is:

$$P = I^2 R_d = \frac{E^2 R_d}{Z^2}$$

If the impedance of the circuit to the waves of the interferent station is Z_1 and to the correspondent station Z_c, we have

$$S_c = P_c/P_1 = Z_1^2/Z_c^2 \tag{40}$$

If the circuit is resonant to the frequency of the correspondent station $Z_c = R_n$ and,

$$S_c = Z_1^2/R_n^2 \tag{41}$$

Let the interferent source be detuned by a small decimal part, P_d, of the resonant frequency. Then,

$X_n = 4 P_d \pi f_n L$ very closely

$$S_c = \frac{16 \pi^2 P_d^2 f_r^2 L^2 + R_n^2}{R_n^2}$$

2. See "Abstractive and Selective Properties of Radio Antenna Circuits," by Edward Bennett. Journal A. I. E. E. 1920, Vol. 39.

$$= 1 + \left(2\,\pi\,P_d\,f_r\,\frac{2\,L}{R_n}\right)^2$$

$$S_c = 1 + (2\,\pi\,P_d\,f_r\,T_c)^2 \quad (42)$$

In most cases the second term is large compared to unity, and for these cases we may write

$$S_c = (2\,\pi\,P_d\,f_r\,T_c)^2 \quad (43)$$

where T_c represents the time constant of the circuit $2\,L/R_n$ and f_r represents the resonant frequency.

Let the selective coefficient (of an antenna circuit) for the interval of excitation, T_e, against a specified detuned frequency be defined to signify the ratio between the energy delivered to the detector by an impressed alternating electromotive force of a frequency such as to make the circuit resonant and the energy delivered to the same detector by an impressed electromotive force of the same value but of the detuned frequency, both electromotive forces being impressed for the same interval of time, T_e.

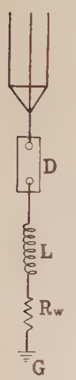

FIG. 9

Let the selective coefficient (of an antenna circuit) for the time interval of excitation T_e (time of Morse dot interval) against a continuous e. m. f. be defined as the ratio of the energy delivered to the detector by the resonant e. m. f. during the time T_e to the energy delivered to the same detector by a continuous e. m. f. both e. m. fs. to have the same peak value.

In a like manner we may define a selective coefficient against a short impulse e. m. f. and a selective coefficient against the first cycle due to a continuous e. m. f.

It is evident that these five coefficients determine to a marked degree the selective properties of an antenna circuit. The first two coefficients determine the selectivity against interferent stations, the last three give indications of the selective properties of the antenna circuit against static.

In the paper referred to above it is shown that for a simple series antenna circuit, similar to the circuit shown in Fig. 9, the values of these coefficients are given by the following expressions

S_c [for steady state against a detuned frequency]

$$= (2\,\pi\,P_d\,f_r\,T_c)^2 \quad (44)$$

S_c [for interval of excitation against a detuned frequency]

$$= 0.8\,(2\,\pi\,P_d\,f_r\,T_c)^2 \text{ if } T_c = 0.2\,T_e \quad (45)$$

S_c [against a continuous e. m. f.]

$$= 2\,\pi^2\,b\,T_e\,f_r^2\,T_c \quad (46)$$

S_c [for first cycle against a continuous e. m. f.]

$$= \pi^2\,b\,f_r^2\,T_c^2 \quad (47)$$

S_c [against a very short impulse]

$$= \frac{b\,T_e\,T_c}{2\,T_1^2} \quad (48)$$

In these equations b is a factor expressing the ratio of the energy actually delivered to the circuit (expended and stored) during the interval of excitation to the energy which would be expended in the resistance if the current in the circuit jumped immediately to its final value and remained there during the interval of excitation.[3]

All of these coefficients vary either as the square of the time constant or as the first power of the time constant T_c. By means of a resistance neutralizer T_c can be increased to almost any desired value by making $R_1 - N$ small enough. It has been shown that the triode circuits may be made to function under all conditions, transient and otherwise, as a resistance neutralizer. In the special case considered, $N = \omega^2\,h$, and R_n or $(R_1 - \omega^2\,h)$ can be reduced to a low value, thus making it possible to obtain a large value for T_c.

In the previous paper, it is shown that for continuous wave telegraphy the upper limit of T_c must not be made much longer than 0.01 sec. if there is to be an interval of silence between dots and dashes at a speed of 30 words per minute. Therefore 0.01 second is taken as the upper limit for T_c. While this value for T_c might be obtained by using small aerials and by taking great precautions to reduce wasteful resistances in the antenna circuit, it may be more readily obtained by using a triode as a resistance neutralizer.

As an example of the lengthening of the time constant due to resistance neutralization, consider the data given in Section 8. C_0 is an antenna, and the circuit is designed from ordinary laboratory inductances. Without the triode the time constant is 0.0005 sec. and with the triode it is 0.0068 second. This example merely serves to indicate how the triode lengthens the time constant. By a proper design of circuits, a time constant of 0.01 sec. can readily be obtained.

11. *Effect of Resistance Neutralization upon the Power which can be Abstracted by an Antenna from Impinging Waves.* If resistance neutralization is not resorted to, the value of the detector resistance which will make the delivery of power from sustained waves to the detector a maximum is:

$$R_d = R_r + R_w \quad (49)$$

where R_d represents the equivalent series detector resistance, R_r the radiation resistance of the antenna with which the detector is associated, and R_w represents the wasteful resistance of the antenna circuit. Let us seek the expressions for the optimum values of R_d with resistance neutralization under the conditions stated in the following problems.

Problem 1. A given antenna has at a given frequency a given radiation resistance R_r and a given wasteful resistance R_w. It is desired to deliver the maximum possible power to a utilization device (detector) having an undetermined resistance R_d.

3. See Curve B, Fig. 6, of previous paper, loc. cit.

A resistance neutralizer is available which will operate reliably (steadily) to reduce the total resistance R_t (or $R_d + R_w + R_r$) to a net resistance R_n, which is γ decimal parts of the total resistance. That is, by the use of the neutralizer

$$R_n = \gamma\,(R_d + R_r + R_w) \qquad (50)$$

What value should be assigned to the detector resistance R_d to make the power delivered to it a maximum when waves of resonant frequency impinge upon the antenna?

The antenna current caused by an electromotive force of r. m. s. value E of resonant frequency is

$$I = E/R_n = \frac{E}{\gamma\,(R_d + R_r + R_w)}$$

The power expended in the detector is

$$P_T = I^2 R_d = \frac{E^2 R_d}{\gamma^2\,(R_d + R_r + R_w)}$$

The value of R_d which makes the power P a maximum as found by equating the derivative of P with respect to R_d to zero and solving, is

$$R_d = R_r + R_w \qquad (49)$$

If R_d has this value,

$$R_n = 2\,\gamma\,(R_r + R_w) \qquad (51)$$

and

$$P_T = \frac{E^2}{4\,\gamma^2\,(R_r + R_w)} \qquad (52)$$

Problem 2. In the problem above, no lower limit was placed upon the value of the net resistance, and in satisfying the conditions for maximum power the net resistance was reduced to $2\,\gamma\,(R_r + R_w)$. But suppose this low net resistance results in a circuit time constant which is of prohibitive length. In other words, let it be assumed that it is not permissible to reduce the net resistance R_n below a specified value R_m. Under these limiting conditions the value assigned to R_d must be such as to make R_n or $\gamma\,(R_d + R_r + R_w)$ not less than R_m. That is, R_d must not be less than (but may be greater than) $(R_m/\gamma) - (R_r + R_w)$. If $[(R_m/\gamma) - (R_r + R_w)] > (R_r + R_w)$, or if $R_m/\gamma > 2\,(R_r + R_w)$, the value which must be assigned to R_d in order to limit the net resistance R_m (or the time constant) as specified above is as follows:

$$R_d = (R_m/\gamma) - (R_r + R_w) \qquad (53)$$

This is greater than the value for maximum power delivery.

On the other hand, if $R_m/\gamma \lesseqgtr 2\,(R_r + R_w)$, the value to be assigned to R_d is the optimum value specified in equation (49).

If $R_m/\gamma = 2\,(R_r + R_w)$, this optimum value makes the net resistance R_n just equal to the lower limit R_m for the net resistance, or gives to the time constant the maximum permissible value.

If $R_m/\gamma < 2\,(R_r + R_w)$, this optimum value makes the net resistance R_n greater than the lower limit R_m, or has the effect of making the time constant shorter than the maximum permissible value.

Problem 3. Now suppose the problem is not that of making the power delivery to the detector a maximum, but the problem is to make the selective coefficient against a sustained wave detuned station a maximum. What is the optimum value for the detector resistance?

We limit the discussion to the general case in which the interferent station is sufficiently dissonant (2 to 5 per cent) to make the net reactance of the antenna to the dissonant frequency large in comparison with its net resistance. From equation (42) it is seen that the selective coefficient of the antenna against an interferent electromotive force which is detuned by a given percentage from the given resonant frequency of the antenna is substantially proportional to the square of the time-constant (T_c) of the antenna. The selective coefficient is independent of the value of the detector resistance, except as the detector resistance may affect the value of the time-constant. If then we are dealing with an antenna of *given* height and capacity, the time-constant of which may not be permitted to exceed a specified value, (such as 0.01 second), two cases arise:

Case I. If the sum of the radiation and the wasteful resistance of the given antenna is so large that $\gamma\,(R_r + R_w)$ by itself is greater than the resistance R_m which corresponds to the maximum permissible time-constant, then the maximum selective coefficient will be obtained if the detector resistance is allowed to approach zero. However the power delivered to the detector at the resonant frequency is a maximum when $R_d = (R_r + R_w)$, and the power decreases to zero as R_d approaches zero.

Case II. If $\gamma\,(R_r + R_w)$ is less than R_m, the value of the selective coefficient is fixed by the value assigned to T_c (or to R_m), and is independent of the value assigned to R_d, provided that $\gamma\,(R_d + R_r + R_w)$ is made equal to R_m.

Before the advent of the resistance neutralizer all antennas fell under Case I. By the proper use of neutralizers all antennas may be made to fall under Case II. The question which now arises is this. If the maximum selective coefficient possible by the use of single tuned circuit has been obtained by satisfying the relation

$$\gamma\,(R_d + R_r + R_w) = R_m \qquad (53)$$

in which, R_m is the resistance which gives the maximum permissible time-constant, what further conditions should be satisfied to make the power delivered to the detector resistance at the resonant frequency a maximum? Two sub-cases arise under this Case II.

Sub Case A. In this case we have a *given* antenna whose dimensions are not to be changed. The only thing which may be varied is the detector resistance R_d. Since in this case the values of both R_m and of the selective coefficient are fixed by the assignment of a

value to the time-constant, and since at resonance, R_m alone determines the flow of current per volt induced in the antenna, and since the power delivered to the detector is

$$P = I^2 R_d = (E/R_m)^2 R_d \tag{54}$$

we may formulate the following rule:

To obtain from a *given* antenna the maximum power consistent with a specified time-constant (or selective coefficient), the detector resistance R_d should be made as great as possible consistent with the stable reduction of the total resistance to the net value R_m which is fixed by the specified time-constant.

Sub Case B. In this case the problem is to determine the proportions which the antenna itself should have in order to deliver the maximum power (consistent with the specified time-constant) to a detector when the antenna is used with a neutralizer having a fixed resistance reduction factor γ.

Let

C_0 represent the capacity of the antenna.
L_0 represent the inductance of the antenna circuit.
f_r represent the frequency of the correspondent station
T_c represent the desired time-constant.
R_m represent the net resistance for the specified time-constant.
h represent the height of the antenna network in cm.
s represent the velocity of light, 3×10^{10} cm. per sec.
p_0 represent the permittivity of air 8.84×10^{-14} farad-cm.
F_m represent the peak value of the electric intensity at the antenna in volts per cm.

The expression for the power delivered to the detector is,

$$P = \frac{(F_m h)^2 R_d}{2 R_m^2} \tag{54}$$

To obtain the maximum selective coefficient the value assigned to R_d must satisfy equation (**53**). That is,

$$R_d \text{ must equal } (R_m/\gamma) - (R_r + R_w) \tag{53}$$

In the subsequent discussion the value of the ratio

$$\frac{R_r + R_w}{R_r} \text{ will be represented by } k \tag{55}$$

and k will be treated as a constant. It should be recognized that this is not strictly correct but is an approximation only.

Substituting the value of R_d from (**53**) and (**55**) in the equation for the power, it becomes,

$$P = \frac{F_m^2 h^2}{2 R_m^2}\left(\frac{R_m}{\gamma} - k R_r\right) \tag{54a}$$

An expression for the value of the minimum permissible net resistance R_m in terms of the antenna constants and specified time-constant may be arrived at as follows:

$$f_r = \frac{1}{2\pi\sqrt{L_0 C_0}} \quad \text{or} \quad L_0 = \frac{1}{4\pi^2 f_r^2 C_0}$$

$$T_c = \frac{2 L_0}{R_m} = \frac{1}{2\pi^2 f_r^2 C_0 R_m}$$

From which

$$R_m = \frac{1}{2\pi^2 f_r^2 C_0 T_c} \tag{56}$$

That is, the value of R_m is fixed by T_c, C_0 and f_r.

In any antenna with an extended capacity area at a height h, the expression for the radiation resistance may be written,

$$R_r = \frac{160\pi^2 h^2}{\lambda^2} = \frac{4\pi h^2 f_r^2}{3 s^3 p_0} \tag{57}$$

Substituting the values of R_m and R_r as expressed in equations (**56**) and (**57**) in equation (**54a**), we have the following equation for the power delivered to the detector when the antenna capacity, the detector resistance and the reduction factor γ are so related as to give the specified selective coefficient.

$$P = (F_m h)^2 \, 2\pi^4 f_r^4 C_0^2 T_c^2 \left[\frac{1}{2\pi^2 f_r^2 C_0 T_c \gamma} - \frac{4 k \pi h^2 f_r^2}{3 s^3 p_0}\right] \tag{58}$$

If the radius of the antenna network is so great as compared with the mounting height that the capacity is approximately expressed by the parallel plate formula, namely,

$$C_0 = \frac{p_0 a}{h} \tag{59}$$

the following equation results from the substitution of the value of C_0 from (**59**) in (**58**)

$$P = F_m^2 \, 2\pi^4 f_r^4 p_0^2 a^2 T_c^2 \left[\frac{h}{2\pi^2 f_r^2 p_0 a \gamma T_c} - \frac{4 k \pi h^2 f_r^2}{3 s^3 p_0}\right]$$

To find the antenna height or the antenna area which will make the power a maximum, we take the derivatives of P with respect to (h) or to (a) respectively, equate the derivatives to zero, and solve the resulting equations. Upon doing so, it is found that the antenna should be so proportioned that,

$$\frac{h}{2\pi^2 f_r^2 p_0 a \gamma T_c} = \frac{8 k \pi h^2 f_r^2}{3 s^3 p_0} \tag{59}$$

That is, the values assigned to (h) or to (a) must be such that,

$$R_m/\gamma = 2 (k R_r) \tag{59a}$$

in which case,

$$R_d \text{ will equal } (k R_r) \text{ or } (R_r + R_w) \tag{49}$$

Equation (**59**) may also be written in the form,

$$a h = \frac{3 s^3}{16\pi^3 k \gamma T_c f_r^4} \tag{61}$$

On the other hand if the antenna network is so high

that its capacity is approximately expressed by the formula for an elevated circular disk, namely,

$$C_0 = 8\, p_0 \sqrt{a/\pi} \qquad (62)$$

the following equation results from the substitution of this value of C_0 in equation (58)

$$P = (F_m^2 h^2)\, 128\, p_0^2\, \pi^3 f_r^4\, a\, T_c^2 \left[\frac{1}{16\, \pi^{3/2} f_r^2\, p_0\, a^{1/2}\, \gamma\, T_c} - \frac{4\, k\, \pi\, h^2 f_r^2}{3\, s^3\, p_0} \right]$$

Upon taking derivatives of this value of P with respect to (h) and (a), equating to zero and solving, it is found that the antenna should be so proportioned that,

$$\frac{1}{16\, \pi^{3/2} f_r^2\, p_0\, a^{1/2}\, \gamma\, T_c} = \frac{8\, k\, \pi\, h^2 f_r^2}{3\, s^3\, p_0} \qquad (63a)$$

That is, in this case also the values assigned to (h) and to (a) must be such that,

$$R_m/\gamma = 2\, (k\, R_r) \qquad (59a)$$

Equation (63a) may also be written in the form

$$a^{1/2}\, h = \frac{3\, s^3}{128\, \pi^{5/2}\, k\, \gamma\, T_c f_r^4} \qquad (63)$$

These equations, (61) and (63), give respectively the dimensions which antennas of the parallel plate type and the elevated disk type must have to permit of the maximum power delivery to the detector, and the maximum selective coefficient against detuned frequencies, which is possible with the given resistance ratio k, reduction factor γ, time constant T_c, and frequency f_r. These equations express, not exactly, but only approximately the optimum relations between the antenna dimensions and the four quantities k, γ, T_c and f_r. They are valid only for antennas of the usual proportions found in high power practice; that is, for antennas whose greatest length is short (one eighth or less) in comparison with the wave length.

The total power delivered to the detector associated with a simple series antenna is,

$$P_T = \frac{h^2 F_m^2}{2} R_d/R_m^2 \qquad (54)$$

If

$$R_d = (R_r + R_w) = k\, R_r \qquad (49)$$

equation (54) may be written

$$P_T = \frac{h^2 F_m^2}{8\, \gamma^2\, k\, R_r} \qquad (65)$$

Of the total power P_T, the amount P_B abstracted from the impinging waves is

$$P_B = \frac{h^2 F_m^2}{8\, \gamma\, k\, R_r} \qquad (66)$$

and the amount P_A supplied by the neutralizer is

$$P_A = (1/\gamma^2 - 1/\gamma)\, \frac{h^2 F_m^2}{8\, k\, R_r} \qquad (67)$$

By substituting the value of the radiation resistance from (57) in equation (66) the following expression is obtained for the power which is abstracted from the impinging waves and delivered to a detector resistance proportioned for maximum power as in equation (49).

$$P_B = \frac{3}{16\, \pi\, k\, \gamma} (s\, \lambda^2)\, (\frac{1}{2}\, p_0\, F_m^2) \qquad (68)$$

In a previous paper,[4] the factor $(s\, \lambda^2)\, (1/2\, p_0\, F_m^2)$ is shown to represent the power flowing across a *wave length square* at the receiving station. Therefore, the greatest power which can be delivered to a detector by an antenna from impinging sustained waves is

$$\frac{3}{16\, \pi\, k\, \gamma}$$

times the power flowing across a *wave length square* at the receiving station.

In the previous paper the factor $1/k$ was termed the *abstractive factor* of the antenna. With a neutralizer associated directly with an antenna the expression for the abstractive factor A_f of the antenna becomes

$$A_f = \frac{1}{k\, \gamma} \qquad (69)$$

Equation (69) shows that the power abstractive factor of any existing antenna can be increased by associating with the antenna a resistance neutralizer, but it should be realized that the increase in the abstractive factor is accompanied by an increase in the time constant of the antenna. If then the antenna circuit without the neutralizer has the longest time constant which is permissible at the sending speed (for example 0.01 second at 30 words per minute), increased power from the waves can be obtained only by increasing the dimensions of the antenna. This may be readily seen by examining the expression giving the proportions which an antenna of the parallel plate type must have for maximum selective coefficient, namely equation (61)

$$a\, h = \frac{3\, s^3}{16\, \pi^3\, k\, \gamma\, T_c f_r^4} \qquad (61)$$

From this it is seen that if k and f_r are fixed, and if T_c is to remain constant, the volume under the antenna must be proportional to the reciprocal of the reduction factor of the neutralizer.

The time constants of existing antenna circuits are short (from 0.0001 to 0.001 sec.), and the selective coefficients of existing circuits can be greatly increased by the use of properly designed resistance neutralizers with both the antenna circuit and its secondary. Resistance neutralization *in the secondary* is to some extent utilized in present radio sets when the thermionic amplifier associated with the secondary is regeneratively coupled. This effect does not however extend back into the antenna circuit.

From the relations brought out in this and the pre-

4. loc. cit.

ceding section it is evident that *pure resistance neutralization as obtained from the Fig. 8 circuit* does not make it possible to obtain a higher selective coefficient against detuned stations than it is *hypothetically* possible to obtain by proper antenna design. That is to say, the selective coefficient against a frequency detuned by a given per cent is fixed by the value of the operating frequency and of the time constant (equation **43**), and calculations indicate that the maximum permissible time constant at a sending speed of 30 words per minute (0.01 second) can be obtained without resorting to resistance neutralization. (This has not been verified by experiment). In general, however, and particularly in the case of the long wave lengths, it will be far cheaper to obtain the desired time constant and selectivity by associating resistance neutralizers directly with antenna, secondary and tertiary circuits rather than by the construction of circuits which in themselves have time constants of 0.01 second.

Pure resistance neutralization as obtained in Fig. 8 increases the selective coefficient of a circuit at the expense of an increase in the time constant of the circuit. A limit to the selective coefficient which may be obtained by this method is set by the fact that in a

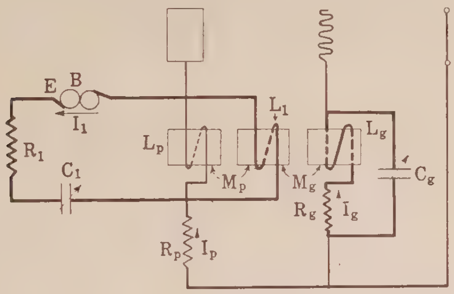

Fig. 10

make and break telegraph system, the time constant cannot be allowed to exceed a definite value. We now proceed to consider types of neutralizer circuits which will increase the selective coefficient of a circuit by methods other than the straightforward method of increasing its time constant.

12. *Circuits which Neutralize Resistance for a Narrow Range of Frequencies near a Desired Frequency and Introduce Resistance and Reactance at other Frequencies.* In the discussion of the triode as a resistance neutralizer, it has been shown that if the circuit is to function as a resistance neutralizer, the ratio E_p/E_g must be less than the ratio G_{cp}/G_p, and the grid voltage E_g must have a component 180 degrees out of phase with the plate voltage E_p. Now, if the grid inductance L_g of Fig. 8 is shunted by a condenser, the magnitude of the grid voltage and its phase position relative to the plate voltage will be a function of the frequency of the current flowing in circuit 1. These considerations at once suggest the possibility of adjusting the circuit and triode constants so as to obtain resistance neutralization for a narrow range of frequencies near a desired frequency and to obtain the effect of an added positive resistance and additional reactance in circuit 1 at frequencies removed from the desired frequency.

Such a circuit is shown in Fig. 10. Let the constants of the circuit be designated as shown on the diagram. The steady-state equations will now be derived by means of the complex algebra. As in the previous case, M_p and M_g represent the algebraic values and not the absolute values of the mutual inductances.

A summation of the voltages around circuit 1 yields the equation,

$$E - R_1 I_1 - j\,\omega\, L_1 I_1 + \frac{j\, I_1}{\omega\, C_1} - j\,\omega\, M_p\, I_p - j\,\omega\, M_g\, I_g = 0 \tag{85}$$

A like summation around the grid circuit yields,

$$-j\,\omega\, M_g\, I_1 - R_g\, I_g - j\,\omega\, L_g\, I_g + \frac{j\, I_g}{\omega\, C_g} = 0 \tag{86}$$

The voltage of the grid is,

$$E_g = -\frac{j\, I_g}{\omega\, C_g} \tag{87}$$

The plate voltage is,

$$E_p = -R_p\, I_p - j\,(\omega\, M_p\, I_1 + \omega\, L_p\, I_p) \tag{88}$$

The plate current is given by the equation

$$I_p = G_{cp}\, E_g + G_p\, E_p$$

$$= G_{cp}\frac{-j\, I_g}{\omega\, C_g} + G_p\,(-R_p\, I_p - j\,\omega\, M_p\, I_1 - j\,\omega\, L_p\, I_p)$$

$$I_p = -\frac{j\left[\dfrac{G_{cp}\, I_g}{\omega\, C_g} + \omega\, M_p\, G_p\, I_1\right]}{D + j\,\omega\, L_p\, G_p} \tag{89}$$

in which $D = 1 + R_p\, G_p$ **(29)**

Upon solving (**86**) for I_g, we have

$$I_g = -\frac{j\,\omega\, M_g\, I_1}{Z_g} \tag{90}$$

in which

$$Z_g = R_g + j\left(\omega\, L_g - \frac{1}{\omega\, C_g}\right) \tag{91}$$

Substituting the value of I_g from (**90**) in (**89**),

$$I_p = -\frac{\dfrac{M_g\, G_{cp}}{C_g\, Z_g} + j\,\omega\, M_p\, G_p}{D + j\,\omega\, L_p\, G_p}\, I_1 \tag{92}$$

Substituting the values of I_g and I_p from (**90**) and (**92**) in (85), and solving,

$$E = I_1\Bigg[\Bigg\{R_1 + \omega^2\frac{M_p^2\, G_p\, D}{W} + \frac{\omega^2}{Z_g^2}\, M_g^2\, R_g - \frac{\omega\, X_g}{Z_g^2}\,\frac{S\, D}{W} - \frac{\omega}{Z_g^2}\,\frac{S\, R_g\, P}{W}\Bigg\}$$

$$+ j\Bigg\{X_1 - \omega^2\frac{M_p^2\, G_p\, P}{W} - \frac{\omega^2\, X_g}{Z_g^2}\, M_g^2$$

$$+ \frac{\omega X_g}{Z_g^2} \frac{S P}{W} - \frac{\omega}{Z_g^2} \frac{S R_g D}{W} \Big\} \Big] \tag{93}$$

in which

$$D = 1 + R_p G_p$$
$$P = \omega L_p G_p$$
$$W = D^2 + P^2$$
$$S = \frac{M_g M_p G_{cp}}{C_g}$$
$$X_1 = \omega L_1 - \frac{1}{\omega C_1}$$
$$X_g = \omega L_g - \frac{1}{\omega C_g}$$
$$Z_g = \sqrt{R_g^2 + X_g^2}$$

In equation (93) the expressions for the resistance and the reactance each contain five terms. The first

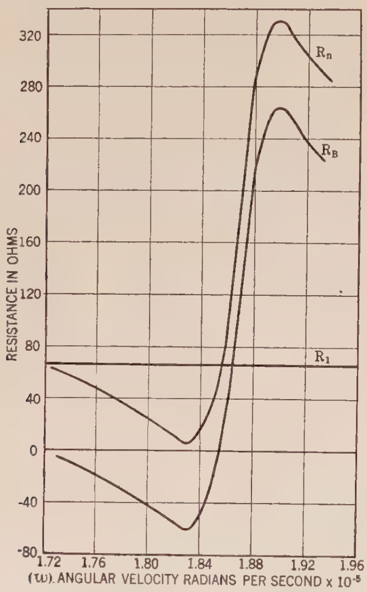

FIG. 11—RELATION BETWEEN RESISTANCE AND IMPRESSED FREQUENCY

R_B—Resistance due to neutralizer.
R_1—Ohmic resistance of circuit.
R_n—Net resistance.

term is the resistance or reactance of circuit 1, the second term represents the effect of the current which flows in the plate circuit by reason of the plate conductance, the third term represents the effect of the alternating current circulating around the divided portion of the grid circuit, and the fourth and fifth terms represent the effect of the current in the plate circuit which is the results of the grid control.

The fourth term is the important term in the expression for the resistance. It changes sign as the impressed frequency passes through the resonant frequency of the circulatory portion of the grid circuit, contributing a positive resistance on one side and a negative resistance on the other side of this resonant frequency. The first and fifth terms are the important terms of the expression for the reactance. The fifth term becomes large for frequencies near the resonant frequency of the grid circuit and may be used to increase the steepness of the curve between the resultant reactance of circuit 1 and the impressed frequency.

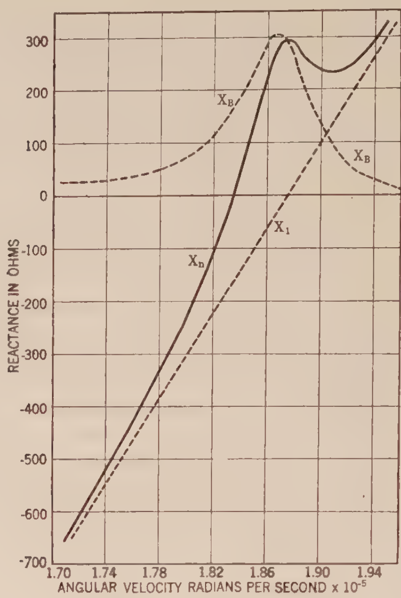

FIG. 12—RELATION BETWEEN REACTANCE AND IMPRESSED FREQUENCY

$X_1 = \omega L_1 - \frac{1}{\omega C_1}$

X_B—Reactance of circuit 1 due to triode.
X_n—Net reactance of circuit 1.

To obtain a better idea of the relations expressed in equation (93), let us apply this equation to a particular circuit by plotting the resistance and reactance of the circuit as functions of the frequency of the alternating

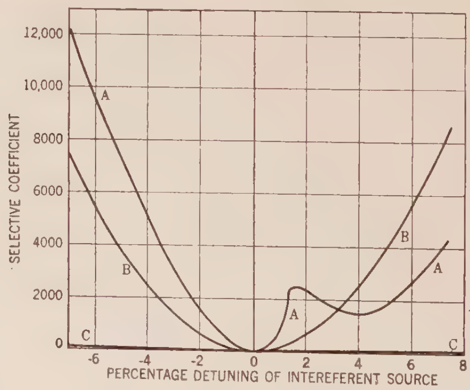

FIG. 13—STEADY STATE SELECTIVE COEFFICIENTS

A—Triode associated with circuit as per Fig. 10.
B—With pure resistance neutralization.
C—Without triode.

electromotive force impressed in circuit 1. Let the coupling be as represented in Fig. 11, that is M_p is positive and M_g is negative. The constants of the circuit with the exceptions noted below are to be the same as given in Section 8 for Fig. 8. The exceptions are:

$R_1 = 66$ ohms
$M_g = -35.7$ microhenries
$C_g = 16.6$ microfarads
$\omega_{rg} = 1.8715 \times 10^5$ rad. per sec.

The curves of Fig. 11 show how the net resistance of circuit 1 varies with the impressed frequency, while those of Fig. 12 show the variation of the reactance with the frequency. An examination of these curves shows that the circuit constants have been proportioned so that the net resistance is near the minimum value at the angular velocity of 1.84×10^5 radians per second, at which the net reactance is zero. It will be seen that the slope of the curve for the net reactance is much greater near this angular velocity than is the slope of the curve X, showing the reactance of circuit 1 without the neutralizer associated with it. This means that the selective coefficient against frequencies detuned by a few per cent is much greater than for a Fig. 8 connection in which pure resistance neutralization is alone utilized.

The selective coefficients, against frequencies detuned by one or more per cent, of a circuit having the constants of circuit 1 of Fig. 10 have been plotted in Fig. 13 for the following conditions. The steady-state selective coefficient is given by the expression,

$$S_c = Z_1^2/Z_c^2 \tag{40}$$

If the correspondent station has a wave length corresponding to = 183,500 radians per sec., $Z_c = 6$ ohms. Z_1 for any other frequency can be found by combining the resistance values given by curve R_n of Fig. 11 and the reactance values given by curve X_n of Fig. 12. The manner in which the selective coefficient varies with the dissonant frequency in this circuit when the correspondent has a wave length corresponding to an angular velocity of 183,500 radians per sec. is shown by curve A of Fig. 13.

Curve B shows the selective coefficient of the same power circuit for the case in which the neutralizer circuit is adjusted (as in Fig. 8) to give *pure resistance neutralization*, reducing the net resistance of the circuit to 6.0 ohms. For curve B and for curve C the angular velocity of the correspondent station was taken as 187,500 radians per second. Curve C shows the selective coefficient of circuit 1 without resistance neutralization, its net resistance at the resonant frequency being the resistance R_1 of 66 ohms. The increased selectivity against frequencies detuned by 1 or 2 per cent which results from the rapid increase of the reactance and the addition of resistance at frequencies slightly removed from the resonant frequency is illustrated by these curves.

Summary. The paper has been summarized in the review of the subject which is printed at the beginning of the paper.

Appendix A

Compilation of Symbols

A_f represents the abstractive factor of the antenna
A stands for the amplifier or resistance neutralizing device
a represents the area of the antenna network in sq. cm.
B stands for the generator or device supplying the driving force
b represents a factor expressing the ratio of the energy actually delivered to the circuit (expended and stored) during the interval of excitation to the energy which would be expended in the resistance if the current in the circuit jumped immediately to its final value and remained there during the interval of excitation
C represents capacity
D represents the expression $1 + R_p G_p$
F_m represents the peak value of the electric intensity in volts per cm.
f_r represents the resonant frequency of the antenna circuit
G_{cp} represents the controlled plate conductance

$$= \frac{\Delta I_p}{\Delta E_g}\ ;\ (E_p = K)$$

G_p represents the plate conductance

$$= \frac{\Delta I_p}{\Delta E_p}\ ;\ (E_g = K)$$

G_g represents the grid conductance

$$= \frac{\Delta I_g}{\Delta E_g}\ ;\ (E_p = K)$$

G_{cg} represents the controlled grid conductance

$$= \frac{\Delta I_g}{\Delta E_p}\ ;\ (E_g = K)$$

h represents a resistance neutralization factor or the height of the antenna network in cm. according to the text
j represents the rotative operator
k represents the resistance ratio of the antenna

$$= \frac{R_r + R_w}{R_r}$$

L represents self inductance
M represents the mutual inductance
N represents the negative resistance due to the neutralizer
P_T represents the total power delivered to the circuit or device under consideration
P_B represents the power delivered by the generator or driving forces to the circuit or device under discussion

P_A represents the power delivered by the resistance neutralizer to the circuit or device under discussion

P_0 represents the power delivered by the generator with the resistance neutralizer removed from the circuit

p_d represents the decimal part of the resonant frequency by which the interferent source is detuned

p_0 represents the permittivity of air (8.84×10^{-14} farad — cm.)

q represents quantity of electricity

R_w represents the wasteful resistance of the antenna circuit

R_d represents the detector resistance

R_r represents the radiation resistance

R_n represents the net effective resistance of the circuit

R_m represents the minimum allowable circuit resistance

R_t represents the total resistance of the circuit

S_c represents the selective coefficient

s represents the velocity of light

T_c represents the time constant of the circuit $\left(\frac{R}{2\,L}\right.$. Simple series circuit $\left.\right)$

T_e represents the length of the time interval of excitation

T_i represent the length of the time interval of a voltage impulse

X represents reactance

Z represents impedance

λ represents the wave length

γ represents $\frac{R - N}{R}$, the resistance reduction factor of the neutralizer when associated with a circuit of resistance R.

ELECTRIFICATION OF ITALIAN RAILWAYS

In a report recently received from P. Tuccimei, official correspondent of the National Association of Italian Engineers for the States of North America, considerable progress is indicated in the electrification of the Italian railways and the use of hydroelectric power. It is stated that within the very near future more than one-tenth of the railroads of Italy will have been electrified.

The report begins by giving figures noting that by "electrified miles" is meant the total mileage of electrified road, including double tracks and yard tracks.

At the end of August 1920 the electrified roads aggregated 524 miles.

Between September 1st and June 30th 1921, five lines were electrified with an aggregate length of 289 miles.

Within the first six months of 1922 five more lines will be electrified with a total of 329 miles.

The electrification of the following lines has already been started: Roma-Tivoli; Roma-Nettuno; Sestri Levante-Livorno; Genova-Ovada-Alessandria: Total mileage, 669.

The result of these past and future accomplishments are noteworthy. The saving in fuel alone to June 30th, 1921 has reached the 160,000 tons. It is estimated that from July 1st 1922 the saving in coal will reach the 200,000 lire a day, or over 70 millions lire a year.

For the lines electrified prior to August 1920 the only power house operated by the State Railways was that of Morbegno, with about 5000 h. p. of installed power and about 3800 h. p. actually used.

The rest of the electric power necessary to operate these lines was supplied on contract by the Dinamo, Edison, Maira and Negri companies.

Some time ago the second section of the Superior Council of Waters approved in its general outline an extremely important scheme of contract for the supply of electric power and for the electrification of the Bologna-Milano road, to be awarded to private contractors.

Contractors who intend to compete for the work will be invited to bid; and the one making the bid considered technically and financially most convenient will be called to work out the details of the contract. The plans will then be submitted to the Board of Administration of the Railroads for their final approval.

Projects and schemes of contracts for the electrification of the Firenze-Empoli-Pisa line, and of part of the lines in the Venezia Giulia and Veneto districts, are also almost ready to be submitted for approval to the second section of the Superior Council of Waters.

Furthermore, the electric output of the Bardonecchia plant will be increased to 20,000 kw. with a yearly output of over 50 million kw-hr. This result will be attained by completing before the end of this year the Rochemolles canal in addition to the Melezet Canal already in operation.

The hydrographic basins of the Reno and Limentra will both be more intensely exploited by storing and conveying to the power houses in course of construction the waters from other affluents of the Reno and Limentra, with an installed power of 40,000 kw. and a yearly output of 80 millions kw-hr. The Sagittario plant in Abruzzo is also in course of construction and will have an installed power of 20,000 kw. and an output of about 70 millions kw-hr. a year.

The plans for the utilization of the discharge waters of the several plants have not been neglected: For the Bardonecchia plant, for instance, projects are under way and nearly finished for two successive falls at Ouly and Salbertrand. For those of the Reno and Limentra, plans are being studied for three successive drops along the tract of the river between Castrola and Sasso.

Selection of Electrical Apparatus for Cranes

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Review of the Subject.—*This paper is intended to assist crane designers and electrical engineers in mills and factories to select the proper size and kind of motor by mathematical calculation from given data, and refers particularly to the electric overhead traveling crane. The paper does not apply to heavy duty cranes which undergo regular duty cycles, nor to very small hoists such as the monorail hoist. It is hoped that at some future date someone else will write papers on these two kinds of cranes to supplement this paper.*

Cranes are classified here for purposes of reference within the paper. It is then shown how to calculate the power required of a motor for hoisting and how to select the particular kind of motor needed; the same information is given for bridge travel with particular reference to the live loads or accelerating loads, and also for trolley travel.

The paper discusses direct-current motors separately from alternating-current motors. The calculations for each are also given separately.

This is the first of a series of papers covering the field of applications of electrical equipment. This paper is on application of motors to cranes. One will follow by Mr. H. W. Eastwood on auxiliary electrical equipment such as magnetic friction brakes, overload protective panels, and limit switches. To complete the series it is planned to have the third paper on the subject of controller equipment.

CONTENTS

IN the selection of electrical apparatus for crane drives, it is first necessary to consider the various classes of cranes. For reference later, these classes are enumerated below:

Class 1. Stand-by or service cranes which are used in emergencies, and at rare intervals. A typical example is the power house crane which is used during installation and thereafter only when repairs are made. The apparatus on such a crane should be simple and should be worked to the limit of its capacity. The control should be very accurate for placing large machines even when used by unskilled operators, as this kind of crane is so rarely used that there is no regularly trained operator for it.

Class 2. Machine-shop and foundry cranes, which are always in service and moderately busy. The apparatus on them should be simple but not worked so nearly to the limit of its capacity as in Class 1. There is always a regular operator in attendance and, therefore, the control apparatus does not necessarily have to be so accurate as in Class 1. In this same class belong loading cranes which serve storage yards where infrequent movement of the stock occurs.

Class 3. High-duty cranes such as are used for moving material in steel mills and for loading material into cars from storage yards where stock is frequently moved. On these cranes very strong apparatus is required, and complications are warranted to some extent in order to secure long life of the apparatus. All apparatus should be very conservatively rated.

Class 3A. Magnet Cranes. On these cranes the hoist motion must be especially chosen so as to stand two times normal load because sometimes two times normal load sticks to the magnet for an instant while it is separating bars from their neighbors. The bridge and trolley motions must be chosen for frequent round trips, probably 60 trips an hour.

Class 4. Soaking pit, charging and stripper cranes. On these cranes fire-resisting insulation is required on motors, and apparatus should be designed to be mechanically strong, conservative in size and exceptionally safe in operation.

Class 5. Hot metal ladle cranes. These cranes should have fire-resisting insulation and should be extremely conservatively designed.

This article will not discuss various small foundry jib cranes and others of this same kind which are operated by a man on the floor rather than by an operator who rides with the crane.

General Selection of Electrical Equipment. To assist in selecting the general type and arrangement of electrical equipment, Table I has been compiled, in which all the various features to be considered are pointed out.

Calculation of Power for Hoisting. The horse power of the lifting motor depends upon the work done on the load, and the power absorbed in the resulting friction of the gearing, journals and pulleys. This quantity varies to some extent with the number of reductions and the type of gearing. The efficiency of a crane is generally lowest at the test, improving somewhat as the journals and teeth wear down,

To be presented at the Spring Convention of the A. I. E. E., April 19-21, 1922.

The efficiency of the first or motor reduction with well-made machine-cut spur gears, running in an oil-bath, has been found by trial to be as high as 97 per cent, and may be taken at 95 per cent under ordinary practical conditions. The average efficiency of one reduction of cut spur gears, running dry, is 92 or 93 per cent, and of cast spur gears, running dry, 90 per cent. The loss due to journal friction is generally about 2 per cent for each axle, when properly lubricated. The only other loss in efficiency of any importance is in the snatch block, if there is one fitted to the crane. This quantity is always reduced by using large pulleys and, preferably, small hardened pins, the pulleys being bushed with gun-metal, under which condition the efficiency works out to about 97 per cent.

$$\text{h. p.} = \frac{W \times S}{33{,}000 \times e} \qquad (1)$$

where h. p. = horse power to hoist at full speed. (All starting resistance short-circuited) (2)

W = weight of suspended load in pounds including tackles (3)

S = speed of hook in feet per minute (4)

e = necessary factor to allow for friction losses in the crane (5)

The value of e varies from 0.25 on low-speed (10 ft. per minute) cranes which use worm gears, to 0.70 for high-speed (75 ft. per minute) cranes which use good cut gears. The over-all mechanical efficiency of a crane can be determined, if the number of reductions and the other particulars are known. Small high-speed cranes have a higher efficiency than larger ones, owing to there being less gearing; thus, in the case of a trolley lifting three tons on a single rope and having two reductions of machine-cut gearing, the first of which runs in oil, the over-all efficiency will be about:

$$\frac{95 \times 92 \times 98 \times 98}{100} = 84 \text{ per cent.}$$

As another example, take a 50-ton trolley having four reductions, the first three of which are machine-cut, the motor reduction running in oil. Then the over-all efficiency will be about:

$$\frac{95 \times 93 \times 93 \times 90 \times 98^4 \times 97}{100} = 66 \text{ per cent.}$$

$$T = \frac{5250 \times \text{h. p.}}{\text{r. p. m.}} \qquad (6)$$

T = Torque on motor shaft required to hoist as in (1) expressed in pounds at one foot radius (7)

r. p. m. = Speed of motor shaft in revolutions per minute with all resistance cut out of the circuit (8)
(This corresponds to S in (4))

$T_1 = T \times e^2$ if no friction brake is used for lowering (9)

where

T_1 = braking torque in pounds at one foot radius required to lower the weight W (10)

The torque to hoist an empty hook or drive it down is about 5 to 30 per cent of the torque required to hoist maximum rated load of the crane. This is due entirely to crane friction.

In addition to the work of hoisting (1) there is the work of accelerating. Most of this work, on cranes lifting at less than 150 ft. per min., is expended on the motor armature and brake wheel. An approximate rule is to assume that the horse power input to accelerate an armature and brake wheel to full speed in one second is equal to the 30-minute horse power rating of the motor for alternating-current induction motors (11); and is equal to one-half the 30-minute horse power rating of the motor for series-wound direct-current motors (12).

A more exact rule is to obtain from the motor manufacturers the weight and radius of gyration of the armature. Then, horse power input to start =

$$\frac{M \times \text{r. p. m.}^2}{1{,}612{,}800 \times t} \qquad (13)$$

where

M is given in (19)

r. p. m. = speed of motor shaft as in (8)

t = seconds used in acceleration (usually not over 2 sec.) (16)

Selection of D-C. Hoist Motors. The general requirements are that the motor shall be enclosed to protect its commutator from dirt, that it shall be as light and easy to start as is consistent with necessary mechanical strength, that it shall be accessible and its parts easily replaceable. The power requirements are for a large torque sustained for only a short time—therefore an especially designed motor for crane service is needed. It differs from a motor which is used for continuous drive in that it requires the mechanical strength of a large motor, the commutating capacity of a large motor, but needs to have only the active electrical material of a small motor. The smaller the active electrical material and the closer it can be located to the armature shaft, the better the motor, because of the lightness and small flywheel effect which are advantageous for a motor that starts frequently and quickly.

Manufacturers of crane motors have given especial attention to the question of commutation either by using large brush area and narrow commutator bars with many windings or by using commutating poles.

When required to meet the modern requirements of dynamic braking control, the motor must be stable and have good commutation when separately excited and when run at a high speed delivering about 50 per cent

of the rated torque; and it must show equally good commutation in either direction of rotation without shifting the brushes.

It is advantageous for these motors to have split frames, easily accessible connection cables and brushes, so that the motor can be readily dismantled and repaired in a small cramped space in the quickest possible time.

To select the proper size of motor for crane hoist, determine (a) the maximum horse power to be delivered by the motor, and (b) the usual horse power. The horse power value obtained by adding h. p. (**1**) for a maximum load to h. p. (**13**) (or, for approximate results to h. p. (**11**) or (**12**)) should always be less than the motor's commutating limits. This may be the five-minute rating of the motor if commutating poles are used. By formula (**1**) the horse power delivered under usual operating conditions should be determined. This usual value of horse power determines the ordinary rating of the motor and it should be:

For Class 1 cranes, the 15-minute rating of the motor.

For Class 2 cranes, the 15- or 30-minute rating of the motor.

For Class 3 cranes, the 60- or 90-minute rating of the motor.

For Class 3A cranes, the 90-minute rating of the motor (because of the uncertainty of the load when the magnet attracts too large a piece).

For Class 4 cranes, the 60- or 90-minute rating of the motor.

For Class 5 cranes, the 30-minute rating of the motor.

On large cranes of Class 5, it is customary to use two hoist motors, each of which alone can hoist the total load without exceeding its commutating limits. This excess capacity is warranted on account of the great value of the metal and the necessity of hoisting the load even if one motor is broken down.

Example of Selection of Direct-Current Hoist Motors. Take a crane which usually hoists 10,000 (W) lb. at 20 (S) feet per minute and which has gear efficiency (e) of 0.55. Take the extreme load to be 15,000 lb. Substitute in (**1**).

$$\text{h. p.} = \frac{10{,}000 \times 20}{33{,}000 \times 0.55} = 11 \text{ h. p. to hoist usual load.}$$

Let t in (**16**) be 2 seconds

$$\text{Then} \qquad \text{h. p. } (\mathbf{12}) = \frac{11}{2 \times 2} = 2.75.$$

When the motor has to hoist 15,000 lb. occasionally this will require approximately

$$\frac{15{,}000}{10{,}000} \times 11 = 16.5 \text{ h. p.}$$

Therefore, the usual horse power required will be 11 and on extreme loads $(16.5 + 2.75 = 19.25)$. Choose a motor which will start at 19.25 h. p. and whose 15-, 30-, 60- or 90-minute rating, according to class of crane, is 11 h. p.

Approximate Rule. An approximate rule is as follows:

$$\frac{\text{Tons to be hoisted} \times \text{ft. per min.}}{10} = \text{30-min. rating of motor.}$$

Selection of D-C. Bridge Motors. The general characteristics of these motors should be the same as those described for hoist motors. They should be series wound, totally enclosed and have good commutating characteristics, etc.

Calculation of Power for Bridge Motors. Rolling friction is caused by axle friction and wheel friction. With good lubrication, axle friction in pounds

$$= \frac{0.10 \times (\text{axle radius in inches}) \times (\text{load in pounds})}{\text{Radius of wheel in inches}}$$

With good track, wheel friction in pounds

$$= \frac{0.002 \times (\text{load in pounds})}{\text{Radius of wheel in inches}}$$

The cross shaft runs in several bearings and its efficiency may be around 95 per cent.

The efficiencies of the gears will be as defined above for hoist motions.

The work done by the bridge motor consists of three parts; first, overcoming track resistance and journal friction—sometimes, together, called rolling friction; second, accelerating the crane with load; third, accelerating the motor armature and brake wheel. The first and second items of work above are done through a train of gears and involve gear losses. In the majority of busy cranes, the rolling friction is a small part of the total work and acceleration is the main work. Usually a draw-bar pull of from 20 to 30 lb. per ton will move a well made crane along a good level track. A new stiff crane or a poor track may require 50 or 60 lb. per ton. Acceleration of the crane and armature may require anywhere from 50 to 300 lb. per ton draw-bar pull, depending on circumstances.

Actual tests show that rolling friction may, for different cranes and tracks, vary anywhere from 5 to 50 pounds per ton. However, when a building sags, the draw-bar pull to move a crane may be almost any value and there is no use of trying to calculate it.

Let C = Weight of crane without load in pounds (**17**)

W = Weight of suspended load in pounds (including tackle) (**3**)

N = Revolutions of motor armature which correspond to one foot travel of the bridge along the track (**18**)

$$\text{in other words } N = \frac{\text{r. p. m. of motor}}{\text{f. p. m. of crane}}$$

M = The effective weight of the armature and brake wheel plus an allowance of 5 per cent for gears, expressed in pounds at one foot radius on the armature shaft, *i. e.* the flywheel effect (19)

$$e = \frac{\text{Efficiency of gearing expressed in per cent}}{100} \tag{20}$$

D = Rolling friction in pounds per ton (21)

V = Free running speed in feet per minute when fully loaded crane is completely accelerated (22)

The easiest way to choose the proper motor is to cut and try. Gear ratio is of vital importance and must be selected to conform to the speed-torque characteristics of the motor.

First determine:

Horse power to propel loaded crane

$$= \frac{V \times D \times \dfrac{C + W}{2000}}{33{,}000 \times e} \tag{23}$$

As a first trial select a motor whose 30-minute rating is about 30 to 50 per cent above horse power in (23). Determine from the motor manufacturer's speed-horse-power curve the speed of the motor when delivering horse power in (23). Then determine N in (18).

Next determine whether the assumed motor with the assumed gear ratio can accelerate the loaded crane and also the empty crane as rapidly as desired or needed, without exceeding the commutating limits of the motor. The rate of acceleration of empty crane will never need to exceed three feet per second per second; and of a loaded crane two feet per second per second.

Let F = torque in lb. at one foot radius at motor shaft corresponding to horse power in (23).

Then $\dfrac{C}{C + W} \times F$ = torque at motor shaft to propel empty crane.

Let A = maximum torque which motor is recommended (by manufacturer) to exert during starting. Commutation and strength will be the limitations rather than heating.

Rate of acceleration in feet per second per second which the empty crane can attain without torque exceeding A

$$= 32.2 \frac{A - \dfrac{C}{C + W} F}{\dfrac{C}{2 \pi N e} + 2 \pi N M} \tag{24}$$

Rate of acceleration in feet per second per second which loaded crane (load being rigid) can attain without torque exceeding A

$$= 32.2 \frac{A - F}{\dfrac{C + W}{2 \pi N e} + 2 \pi N M} \tag{25}$$

It is interesting to note that when the load is hung from the crane by a flexible rope, the motor does not have to start the load as soon as the crane starts. This relieves the motor somewhat. At the first instant of starting, the motor has to overcome rolling friction of total weight of crane and load, and it has to accelerate the crane and armature. As the crane moves away from the load, the load begins to accelerate at a rate far below that of the crane and finally when the crane has moved far enough away from the load, the load is accelerated as rapidly as the crane.

Rate of acceleration in feet per second per second which loaded crane attains at instant crane starts to move (before suspended load begins to move), without torque exceeding A

$$= 32.2 \frac{A - F}{\dfrac{C}{2 \pi N e} + 2 \pi N M} \tag{26}$$

There are four things which tend to limit the rate of acceleration of a bridge motor:

1. Automatic magnetic control can absolutely limit it.
2. Slipping of wheels can practically limit it.
3. Swinging of load can limit it in some cases.
4. Comfort of operator may limit it.

When automatic magnetic control is used, the current-limit devices may be set to a value of current just sufficient to start the crane under the severest working conditions, and if the current is within the working limits of the motor no trouble need be expected on the crane. Of course, trouble can arise if the controller fails to function properly or if the operator "speeds up" the crane by setting the relays for higher current. To safeguard against this last difficulty, it is, of course, necessary to select a motor large enough to make all the speed actually needed. An average acceleration of something like 1 to 1½ ft. per sec, per sec. will be fast enough for cranes which travel at less than 500 ft. per min. or make infrequent starts. Cranes which make regular frequent trips of 50 or 60 ft. every minute or so may need an *average* acceleration of 2 to 2½ ft. per second per second. Cranes which do "stunts" with swinging loads like some bucket cranes, which swing a bucket into a hopper, or hot metal ladle cranes, may need even 3 feet per second per second *peak* acceleration.

When a motor is powerful enough to slip the wheels under full load without exceeding the working limits

of the motor, it is out of danger. A simple calculation[1] shows that if one-fourth of the wheels are driven and if these wheels carry one-fourth of the total weight, an acceleration peak of 2 ft. per second per second will just about slip the wheels. Of course, the average acceleration will be less than the peak and will depend on the number of controller steps.[2] If one-half the wheels are driven, the rates of acceleration could be double the above values. Of course, it is possible for a vicious operator to turn his controller on so rapidly after the wheels slip, that the power required to spin the wheels and accelerate the armature will exceed the motor limits; but this is hardly to be expected. Where it is possible for a crane to do its work with only one-fourth of the wheels driven, this drive makes a very practical way of protecting the motor, but where one-half of the wheels must be driven, the motor is not so protected from overload.

Cranes are frequently used for dragging cars and consequently the bridge motors must be large enough to do extra work, when so used. This problem would be something like an electric locomotive problem and will not be discussed in this paper.

Usually when an enclosed crane bridge motor is properly chosen so far as torque and strength are concerned, it is big enough so far as heating is concerned; but this is not necessarily true on rapid-duty cranes. If the crane is running with power on the motor, more than 35 seconds in 100 seconds continuously for 5 hours at a time, heating is liable to be a limitation and the motor manufacturer should be consulted or past experience with similar work should be used.

Selection of Trolley-Motion, Direct-Current Motors. The type of motor should be the same as for hoist and bridge motions and since this motor is "plugged" (or reversed by power when running at high speed frequently) its commutation must be good at double speed and 150 per cent current. Its commutator and windings must be insulated for at least double normal voltage.

Calculation of Power for Trolley Motors.

Let B = weight of trolley carriage less load **(27)**

V = free running speed in feet per minute when fully loaded trolley is completely accelerated **(28)**

1. Assume a coefficient of friction between the wheels and the rail of 25 per cent. Then the available draw-bar pull from one-fourth of the wheels will be 25/4 or 6.25 per cent of the weight of the crane. Gravity (or the total weight of the crane) will accelerate the crane at 32.2 ft. per second per second—therefore 6.25 per cent will accelerate it at 0.625 × 32.2 or 2 ft. per second per second. This calculation omits some niceties about rolling friction but they are relatively unimportant.

2. Three blocks of accelerating resistors produce an average of approximately 72.5 per cent of the peak rate of acceleration; four blocks 78.5 per cent; six blocks 85 per cent; nine blocks 89 per cent; and thirteen blocks 92.5 per cent.

Horse power to propel loaded trolley

$$= \frac{V \times D \times \dfrac{B + W}{2000}}{33{,}000 \times e} \qquad \textbf{(29)}$$

Choose a motor whose 30-minute rating is not less than horse power in **(29)**

Selection of Alternating-Current Polyphase Hoist Motors

For the usual factory crane an open-type motor should be used.

Where metal dust cinders, furnace fires, acid alkali and such unusual conditions are present, motors should be specially insulated and, in some cases, enclosed.

For cement plants the bearings should be enclosed. It has seemed desirable to enclose also the collector rings but there is a considerable physical difficulty in enclosing collector rings on a motor which is equipped with a solenoid brake at one end and gearings at the other end. These difficulties, together with the inaccessibility of enclosed collector rings, have made it a better practical proposition to use open collector rings. It is necessary to clean out the brushes frequently in order to prevent them from sticking.

The slip-ring wound-rotor induction motors are generally used where reduced-speed operation is needed. The single-speed squirrel-cage-rotor type of motor, with high-resistance rotor windings, is best suited to cranes which handle rough material where no reduced-speed operation is required and where size does not exceed 25 horse power. Under this class would come ice hoists, lumber cranes at not over 50 or 75 ft. per minute, cranes for boxed or baled goods at not over 100 feet per minute, machine shop cranes at not over 15 or 20 feet per minute. The multi-speed motor with squirrel-cage rotor offers many possibilities where reduced-speed operation is required, such as foundry hoists; but this type has not been generally exploited commercially.

There are two important differences between the alternating-current and the direct-current, series-wound motor: (1) Power supply voltage and frequency must be maintained fairly uniform for the alternating-current motor because its maximum starting torque varies as the *square* of the voltage impressed, and inversely as the *square* of the frequency. Voltage has, in practise, no effect on the maximum starting torque of a direct-current series-wound motor because starting torque is a function of current only and even if voltage is abnormally low the controller can be manipulated to give maximum current. It is therefore, necessary to choose

a motor whose maximum-minimum[3] starting torque is, at least, twice and for squirrel-cage motors 2.5 or 3 times the torque required for hoisting the maximum load. Consider, for example, a crane where power supply voltage is 90 per cent of rated motor voltage and where static friction is such as to add 25 per cent to hoisting torque at the instant of starting. Then if motor could exert 200 per cent normal torque at starting under normal voltage, it could exert 162 per cent of normal torque under 90 per cent voltage; and it would be called on to exert 125 per cent of normal torque. The difference between 125 per cent and 162 per cent represents the margin, and it is none too great. This margin is not sufficient for squirrel-cage motors because if they stall they are almost sure to burn out the rotor.

In order to make the same number of trips per day with an a-c. crane as with a d-c. crane, it is frequently necessary to gear the a-c. crane for a higher full-load hoisting-hook speed than would be used with d-c., and this means that the rating of the a-c. motor must be relatively greater than that of the d-c. motor. To explain, let us assume that a round trip consists of hoisting full load 20 feet, lowering it 20 feet, hoisting an empty hook 20 feet and lowering it 20 feet. If a d-c. motor were used and geared for 40 feet per minute full-load hoisting speed, it would hoist in 30 seconds, lower (where lowering speed is 190 per cent hoisting speed) in 16 seconds, hoist in about 15.5 seconds (where 20 per cent hoisting torque corresponds to 195 per cent speed), lower in 20.5 seconds, making a total of 82 seconds. An a-c. motor would have to be geared to hoist full load in about 20.5 $\left(= \frac{82}{4}\right)$ seconds in order to keep up with the d-c. motor because the a-c. motor can never run above its synchronous speed. This means that the a-c. motor would have to be $\frac{30}{20.5}$ (= 1.46) times as large as the d-c. motor for the particular case illustrated. This ratio does not come as high as 1.46 for ordinary practical cases where there is a good deal of creeping speed work in the typical round trip of the crane hoist. However, in order to meet the requirements of an occasional extremely high load, an induction motor may have to be considerably larger than a d-c. motor because a d-c. motor can exert more overload torque.

Use of Permanent Resistance in the Rotor Winding of Slip-Ring Motors. When manual control is used and service is severe and abusive, *a permanent block of resistance* should be wired in series with the slip rings of the motor and should be of such value that the slip at full-load torque on the motor will be about 15 per cent after the controller has been turned to the "full on" position. To accomplish this, the permanent resistance should contain about 10 per cent as many ohms as are required to give 100 per cent slip (or standstill) with full-load torque on the motor. This sounds like wasting power but power is only one of the small considerations in the operation of the crane. The following tabulation of performance values on a certain typical motor shows the advantage of permanent resistance:

Max. stalling* torque in per cent of full-load torque	Stalling amps. in per cent of full load	Per cent slip when motor is delivering full-load torque	Heating when motor is stalled, expressed in per cent of the heating when full-load current is flowing
175	484	5	2340
265	419	10	1750
290	360	15	1300
286	311	20	960
272	278	25	775
255	250	30	625
236	229	35	522
220	208	40	434

*These are maximum-maximum values; not maximum-minimum values.

Operators seem to make a practise of turning these manual controllers on as fast as possible and it is best to plan that the controller will be full on before the motor starts. The above table shows that the most starting torque can be obtained when a resistor is set for 15 per cent slip and that there is a big saving in motor heating at this resistor setting. A careful study of practical operation from all angles will show that with this resistor setting more can be gotten out of the motor than with any other setting, and at less expense in the way of motor and control trouble.

When magnetic control is used, no permanent resistance is necessary because current-limit relays prevent all of the resistance from being short-circuited while the motor is at standstill.

When permanent rotor resistance is used, it is not necessary, in comparing an a-c. motor with a d-c. series motor, to make the full-load hoisting speed for alternating current as much higher than for direct current as was indicated in a foregoing paragraph. In the example used, the full-load lowering speed will be enough above synchronous speed to average up the lower full-load hoisting speed; and, consequently the full-load hoisting speed need be only 129 per cent above

3. Maximum-minimum starting torque is a term which applies to slip-ring type, wound-rotor induction motors. With the external resistance which is connected to the rotor adjusted for obtaining the maximum starting torque, the currents are so high as to set up a magnetic distortion between the poles of the stator and of the rotor. At some positions of the rotor, this distortion causes the torque to increase and at other positions to decrease. Maximum-maximum starting torque means the torque when rotor is in most favorable position; *Maximum-minimum*, the most unfavorable.

full-load d-c. hoisting speed in order to make the round trip in 82 seconds.

Calculation of Power for Alternating-Current Crane Hoist Motors. Calculate the hoisting horse power as per equation (**1**) and choose a motor whose 30-minute rating is equal to or greater than this value. Where the motor is to be started frequently, calculate starting horse power to start from equation (**13**), choose a motor such that horse power from (**1**) plus horse power from (**13**) does not exceed 150 per cent of the 30-minute rating.

Sometimes, on very rough service, it is advantageous to connect a permanent resistor in the rotor circuit of such value that speed under full load is about 85 per cent of the synchronous speed. When this is done the motor rating is reduced about 10 per cent and, therefore, select the motor so that its 30-minute rating is 110 per cent of the horse power in equation (**1**). Also it is, of course, necessary to gear the motor so that when running at 85 per cent of synchronous speed, the load will be hoisted at rated crane hook speed.

Heating is not usually a limiting feature on open motors when motors are selected as above described except on bucket or similar cranes. When enclosed motors are to be used, or buckets are to be handled, the duty should be referred to the manufacturer for selection of the motor.

Selection of Alternating-Current Bridge-Motion Motors. Wound-rotor motors with slip rings are best suited to this work.

Motors should be open, enclosed or specially insulated to correspond with hoist motor.

Permanent rotor resistance is generally advantageous.

Calculation of Power for A-C. Bridge-Motion Motors. Try a motor such that the horse power to propel, in equation (**23**) does not exceed 75 per cent of the 30-minute rating. The maximum instantaneous torque during starting should not exceed 200 per cent of the full-load rated torque of the motor. Refer to equations (**24**), (**25**) and (**26**); substitute for A a value of torque in pounds at one foot radius which is not over twice full-load rated torque. Then see that a satisfactory rate of acceleration can be attained, cut and try until a suitable size of motor is obtained. On some high-speed cranes, horse power in equation (**23**) may have to be as low as 30 per cent of the 30-minute rating of the motor in order to obtain satisfactory acceleration without overloading the motor.

TABLE I

A KEY TO ASSIST IN THE SELECTION OF ELECTRICAL EQUIPMENT FOR CRANES

- Electrical Equipment for Cranes
  - Motors
    - Enclosed or Open, Insulation, Mechanical Strength and Staunchness
    - Rating
    - Accessibility for Repairs
    - A-C.
      - Wound Rotor or Squirrel Cage 1-speed or 2-speed
      - Voltage
      - Frequency
      - No. of Phases
      - Heating Basis
        - 15 minute
        - 30 minute
        - 60 minute
      - Max. Torque
    - D-C.
      - Max. Torque
      - Series or Compound Wound
      - Voltage
      - Heating Basis
        - 15 minute
        - 30 minute
        - 60 minute
  - Control Equipment
    - Controller
      - Drum
        - Straight Reversible
        - Dynamic Braking
        - No. of points
        - Type of handle
          - pump
          - vertical
          - horizontal
          - remote lever
          - rope-wheel
          - spring-return
      - Magnetic
        - Straight Reversible
        - Dynamic Braking
        - No. of hand control points
        - No. of automatic control points
        - Plugging point
          - Hand controlled
          - Automatic
        - Creeping speed point
        - Space requirements
        - Type of handle on master
    - Rheostat
      - Heating
      - Starting Torque
      - Plugging
      - Creeping Speed
    - Brakes
      - Series or Shunt Wound
      - Torque Requirements
      - Staunchness
      - Wearing Qualities
      - disk
      - shoe
      - band
      - coasting distance
  - Protective Equipment
    - Overload
    - No-voltage
    - Emergency Conditions
    - Lock-out on Line Switch
    - Individual Motor Switches
    - Overwind Protection
      - geared / hook-operated
      - relay / main circuit
      - reset / non-reset
      - inherent / extra-wire

Selection of Alternating-Current Trolley Motors. Use the same type of slip-ring motor as on hoist and bridge.

Choose a motor such that the horse power in equation (**29**) does not exceed the 30-minute rating of the motor.

On certain small trolleys which do not exceed 250 ft. per minute speed nor 5 h. p., it is possible to use a simple squirrel-cage motor with high-resistance rotor. Such a motor must have a starting torque at least twice the torque required to propel the maximum load as per equation (**29**).

Starting torque in pounds at one foot radius must at least =

$$2 \times \frac{(\text{horse power in (29)}) \times (\text{full load r. p. m.})}{5{,}250}$$

Special heating requirement must be met and special control precautions taken.

SUPERPOWER SYSTEM FOR JAPAN

Developments in Japan within recent months indicate the future possibility of a superpower system to furnish electricity over the large area between Tokyo and Osaka. It is stated in a paper by Mr. C. A. Powel, of the Westinghouse Electric and Mfg. Co., that the completion of the contemplated program will give this Far Eastern nation one of the largest, if not the largest, superpower systems in the world.

The principal industries in Japan are situated along the south coast of the Island of Nippon, around Tokyo, Osaka and Nagoya. The rough and somewhat sparsely populated provinces of Shinana and Mino are particularly rich in water power, which is capable of development at such a cost as to make transmission to both Osaka and Tokyo an economical proposition. The rivers in this district have already been utilized for power purposes to a certain extent, but it is planned to obtain from them within the next few years an additional half million kilowatts.

The prevailing frequency in the Tokyo district is 50 cycles and in the Osaka district 60 cycles, so that an interchange of power is at the present time not possible, but the power companies serving the two territories will undoubtedly find it to their advantage to arrange for some interchange of power and in the most recent stations the generators, transformers and switchgear are being ordered for service at both 60 and 50 cycles.

This superpower scheme when realized will cover practically the whole of central Japan. At present this territory is served by five companies, all of which are taking part in a development of water power resources which is probably without precedent in the history of engineering. From January 1920 to June 1921, Japan ordered abroad hydroelectric machinery totaling 260,000 h. p. and in the same period manufactured at home 150,000 h. p. of such machinery.

The capacity of the plants recently completed totals 129,500 kv-a., plants building and nearing completion aggregate 273,900 kv-a., and plants to be built in the near future will have a capacity of 327,950 kv-a. These figures include the building programs up to the year 1926. A proposal has been made, and is said to find favor with the present Minister of Communication, to amalgamate all these companies. If this can be brought about, Japan will undoubtedly have the largest power supply concern under one management in the world.

It is interesting to note that this tendency to amalgamate is found not only in Central Japan but also in Hokkaido (the northern island) where the Fuji Electric Company has absorbed the five other companies serving the island, and in Kyushu (the southern island) where an amalgamation of all the companies, large and small, is on the point of realization.

ELECTRIC SERVICE IN MADRID

Among Spanish residents there is increasing criticism of the present service for electric light and electric current in the city of Madrid. To foreigners the light seems weak, especially during the peak hours; and often in the late afternoon electric elevators fail to function. This has become so serious of recent years as to affect the rents obtainable for upper stories of residential and office buildings.

As there are few hydraulic or steam elevators in Madrid, the electric current is a matter of considerable importance to both landlords and tenants, there being about 300,000 persons living in flats in Madrid.

Increased Use of Electric Current

Madrid has found many new uses for electricity, such as in heating and cooking; the municipality has imposed an obligation on landlords to install a light at the entrance of each building; the increased cost of gas has naturally turned many persons toward the use of electricity; industrial progress and extension have also increased its consumption. The progress of the people themselves demands an increasing amount of electricity, since many classes who formerly did without now use it as a matter of course. The working of all these causes has in the last two years brought about an excessive increase in consumption of electric current, so that today the number of subscribers in each of the seven companies exceeds the total number existing in Madrid two years ago, and practically each subscriber consumes more electricity than he did then.

With the present lack of electric current, a real problem must soon be faced when the 1000 buildings now under construction and those planned for imminent erection are finished and added to the consumers of electricity, unless new electrical projects are promptly negotiated.

There is, therefore, a considerable agitation for increasing sources of supply. Along with it there is propaganda for popularizing the schemes already under construction, which represent estimated production of 600,000,000 kilowatts per hour.—*Commerce Reports.*

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A. I. E. E. Spring Convention

CHICAGO, APRIL 19-21

The Spring Convention of the American Institute of Electrical Engineers will be held in Chicago, Ill., April 19-21, 1922. The Institute headquarters during the convention will be in the Drake Hotel, where the technical sessions also will be held.

The Committee of Arrangements for this convention has recently been appointed by President McClellan and its personnel is as follows: Chairman, Louis H. Ferguson; vice-chairman, J. E. Kearns; C. E. Allen, E. E. F. Creighton, Charles H. Jones, S. A. Rhodes and C. J. Schaus. The committee is arranging technical inspection trips and some social features, including entertainment for the visiting ladies.

The technical program which is in the hands of the Meetings and Papers Committee is not yet completed but a number of the papers to be presented has been tentatively scheduled and is as follows:

The Superpower System–I, by Henry Flood, Jr.

The Superpower System–II, by L. E. Imlay.

The St. Lawrence Seaway, by W. L. Saunders.

The Relation of the Electrical Engineer to Fire Prevention and Fire Protection, by R. C. Loughead.

The Electric Hammer, by P. Trombetta.

A Relay Recorder for Remote Control by Radio, by F. W. Dunmore.

Philadelphia-Chicago Long-Distance Telephone Cable, by James J. Pilliod.

Selection of Electrical Apparatus for Cranes, by R. H. McLain.

Auxiliary Electrical Equipment for Motor-Operated Cranes, by H. M. Eastwood.

Textile Printing, by C. T. Guildford (by title only).

The Use of Slip-Ring Induction Motors and Synchronous Motors in Cement Mills, by H. W. Rogers (by title only).

Magnetic Clutches in the Cement Industry, by W. H. Costello (by title only).

Electric Power Application to Passenger and Freight Elevators, by H. P. Reed (by title only).

The Two-Stage Current Transformer, by H. B. Brooks and F. C. Holtz.

Magnetic Flux Distribution in Transformers, by Karl B. McEachron.

The complete program of technical papers and other convention events will be printed in the April JOURNAL.

A. I. E. E. Annual Convention

NIAGARA FALLS, JUNE 26-30

It has been decided to hold the Annual Convention of the Institute this year at Niagara Falls, Ontario, during the week of June 26-30. The headquarters during the meeting will be at The Clifton Hotel.

Preparations for this Convention are well under way. President McClellan has appointed the Committee of Arrangements as follows: F. R. Ewert, Chairman, H. G. Acres, A. W. Berresford, E. E. F. Creighton, W. P. Dobson, L. E. Imlay and J. Allen Johnson. This committee will have charge of all local arrangements, and it is planned that excursions and social events will occupy a portion of each day, for which purpose all of the afternoons will be left open.

The program of technical papers under the auspices of the Meetings and Papers Committee, has been partly arranged but is not sufficiently complete to announce at this time. It is also planned to hold several important meetings and conferences of Sections Delegates.

Further information will appear in successive issues of the JOURNAL as the plans for this convention mature.

Future Section Meetings

Akron.—March 22, 1922, Engineering Society of Akron Rooms, 41 East Mill Street. Subject "Illumination." Speaker: Mr. A. R. Holden, of the B. F. Goodrich Company, Akron.

Atlanta.—March 30, 1922. Subject: "Steam Turbines." Speaker: Mr. E. F. McLaughlin, of the General Electric Company.

Baltimore.—March 17, 1922, Engineers Club, Baltimore, 8:15 p. m. Subject: "The Relation of the Bureau of Standards to the Industries and Engineering Societies of the Country." Speaker: Dr. S. W. Stratton, Director, Bureau of Standards, Washington, D. C.

Cleveland.—March 21, 1922, Club Rooms of the Electrical League, Hotel Statler, 8:15 p. m. Subject "Power Plant Economics with Special Reference to the Steam Turbine." Speaker: Mr. T. E. Keating, of the Westinghouse Elec. & Mfg. Company.

Erie.—March 21, 1922. Subject: "Electrochemistry." Speaker: Mr. Swartz.

Fort Wayne.—March 16, 1922. Subject: "Automatic Substations." Speaker: Mr. W. S. Richhart of the Indiana Service Company. This meeting will include an inspection trip through one or more of the automatic substations of the local traction company.

Lehigh Valley.—March 9, 1922. Subject: "Radio Telephony and Broadcasting." Speaker: Mr. L. W. Chubb, manager of the Radio Engineering Department, Westinghouse Elec. & Mfg. Company, Pittsburgh.

Pittsburgh.—March 15, 1922, Chamber of Commerce Auditorium, Pittsburgh, at 8:00 p.m. The program for this meeting has been arranged especially with a view to interesting the many men who are directly responsible for the operation of electrical machinery in industrial and commercial plants. Program: "Electricity in and around a Coal Mine," by H. J. Nelms, general superintendent, New Fields By-Products Coal Company; "Electrical Problems in the Department Store,"

by E. R. Roberts, mechanical superintendent, Kaufmanns; "Factors Governing Maintenance Policies for Industrial Electrical Apparatus," by Mr. A. C. Cummins of the Duquesne Works, Carnegie Steel Company. All of the speakers have had broad and intimate practical experience in the operation of electrical apparatus. The papers will be discussed by other operating men, by manufacturers and by central station men.

Schenectady.—March 17, 1922. General subject: "Recent Developments in High-Tension Practise and High-Voltage Phenomena." Speaker: Mr. F. W. Peek of the General Electric Company, Pittsfield, Mass.

Toronto.—March 10, 1922. Joint meeting with Toronto Branch Radio Research Club of Canada. Subject: "Wireless and Guided Wave Telephony." Speaker: Mr. Charles A. Culver, Ph. D.

March 24, 1922. Joint meeting with Hamilton Branch Engineering Institute of Canada at Hamilton, Ont.

April 7, 1922. Subject: "Explanations and Demonstrations of Power Factor." Speaker: Professor H. W. Price.

Utah.—March 31, 1922. Commercial Club, Salt Lake City Utah. Subject: "Illumination and Eye Strain." Speaker: Mr. H. T. Plumb, of the General Electric Company.

Vancouver.—April 7, 1922. Auditorium Board of Trade Building, Pender & Homer Streets. Subject: "Safety Card in City and Suburban Service." Speaker: Mr. H. M. Lloyd.

Philadelphia.—March 15, 1922. Joint meeting. Franklin Institute of Philadelphia and Philadelphia Section A. I. E. E.

March 21, 1922. Second Hydroelectric Symposium. Manufacturers' Club. Broad and Walnut Streets. Afternoon and evening sessions.

A. I. E. E. Directors Meeting

FEBRUARY 16, 1922

The regular bi-monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Thursday, February 16, 1922, at 4:00 p. m.

There were present: President William McClellan, Philadelphia; Past President Calvert Townley, New York; Vice-Presidents W. A. Del Mar, New York, and F. R. Ewart, Toronto; Managers W. I. Slichter, L. F. Morehouse, E. B. Craft, H. A. Pratt, New York, G. Faccioli, Pittsfield, L. E. Imlay, Niagara Falls, H. B. Smith, Worcester, R. B. Williamson, Milwaukee, A. G. Pierce, Pittsburgh; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York.

Approval by the Finance Committee of monthly bills amounting to $19,873.43 was ratified.

The Meetings and Papers Committee reported that plans are progressing for the Chicago Convention, April 19-21; the Annual Convention, Niagara Falls, June 26-30; and the Pacific Coast Convention, Vancouver, August 8-11.

Reports were presented of meetings of the Board of Examiners held January 9 and February 10; and the actions taken at those meetings relative to applications for election and transfer were approved. Upon recommendation of the Board of Examiners the following action was taken upon pending applications: 227 Students were ordered enrolled; 291 applicants were elected to the grade of Associate; 11 applicants were elected to the grade of Member; 9 applicants were transferred to the Grade of Member; 1 applicant was transferred to the grade of Fellow.

Announcement was made of the appointment by the President, as required by the Constitution, of the Tellers Committee, to convass and report upon the nomination and election ballots in connection with the 1922 election of Institute officers.

Authority was granted for the organization of an Oklahoma Section of the Institute.

The resignation of Professor Robert J. Scott as Local Honorary Secretary for New Zealand, because of retirement from professional duties, was presented; and Mr. Lawrence Birks was appointed as his successor. A letter of appreciation of Professor Scott's services as Local Honorary Secretary was voted.

In addition to these actions, other matters relating to important activities and the general policy of the Institute were discussed; reference to these matters may be found in this and future issues of the JOURNAL under suitable headings.

The Midwinter Convention

The Tenth Midwinter Convention of the American Institute of Electrical Engineers was held in New York, February 15-17, 1922, at the Engineering Societies Building. By tradition, this annual function of the Institute has become established as a working convention, devoted almost exclusively to the presentation and discussion of highly technical subjects. The program for this year's convention was a full one, averaging four papers for each of the five technical sessions, and a large part of the discussion was prepared in advance, resulting in unusually interesting sessions which were prolonged considerably beyond the usual limits.

In addition to the technical sessions, one evening was devoted to the presentation of the Edison Medal to Mr. Cummings C. Chesney, after which Dr. W. D. Bancroft delivered a lecture on Colloids. One afternoon was reserved for visits to points of engineering interest in New York city and vicinity, and on the last evening of the convention the annual Dinner-Dance was held.

The registration bureau which was in the foyer of the building opened on February 15 at 11:00 a. m., and approximately 1000 members and guests were registered during the three days of the convention.

Various Institute committees held meetings during the Convention as follows:

February 15. Sectional Committee on Lightning Protection, Meetings and Papers Committee, Electrical Machinery Committee, Standards Subcommittee on Switching, Control and Protective Apparatus, Standards Subcommittee on Rotating Machinery, Standards Subcommittee on Telegraphy and Telephony, and Subcommittee on Reactors.

February 16. Board of Directors, Membership Committee, and Industrial and Domestic Power Committee.

February 17. Standards Committee, and Protective Devices Committee.

WEDNESDAY AFTERNOON

The first session was called to order by President McClellan at 2:30 p. m. President McClellan gave a short introductory address bearing on the opportunities of the engineering profession in the readjustment and development of the country following the general derangement of business and manufacturing conditions due to the war. He considered the transportation problem one of the most fundamental and difficult matters which require attention. It is folly to talk about lowering railroad rates with the present railroad systems, but we know that eventually the rates must come down, even if it means the creation of a brand new transportation system. Today railroad electrification is nearer than it ever was before. Most of the technical features of electrification have been solved, and the country will be willing to pour money into the greatest and most fundamental machine of all—the transportation machine—when terminal and other conditions are satisfactory, and when we are certain the machine is right.

President McClellan pointed out that the future would be the era of power, because it is to be the era of machines; that is the reason we hear of the St. Lawrence Seaway being coupled up with waterpower; of the project at Muscle Shoals and other projects for the development of power; of the great Superpower

System recently reported upon by one of the leading members of this Institute. This is going to be an age of power, and therefore an age of opportunity for every type of engineer, and especially the engineer skilled in electrical applications.

The president then introduced Mr. W. H. Martin who presented the first paper on the program entitled *The Key West—Havana Submarine Telephone Cable System*, by W. H. Martin, G. A. Anderegg and B. W. Kendall. The paper was discussed by Bancroft Gherardi. This was followed by the paper entitled *Submarine Cable Telegraphy*, by J. W. Milnor, presented by the author and discussed by W. D. A. Peaslee. The final paper of the session, *Printing Telegraph Systems Applied to Message Traffic Handling*, by A. H. Reiber, presented by the author, was discussed by R. E. Chetwood, John H. Bell and G. D. Robinson.

Wednesday Evening

At the Wednesday evening session presided over by President McClellan the first business was the presentation of the *Questionnaire on Lightning Arresters*, by F. L. Hunt, followed by the paper *On Deviations from Standard Practise in Lightning Arresters*, by E. E. F. Creighton. These papers were discussed by Joseph Slepian, D. W. Roper, Joseph L. R. Hayden and Norman A. Lougee.

The next item was the paper on *Condenser Discharge Through a General Gas Circuit*, by Charles P. Steinmetz which was presented by the author and discussed by A. Karapetoff and L. W. Chubb.

Thursday Morning

At the Thursday morning session, after the opening by President McClellan, E. B. Meyer, Chairman of the Transmission and Distribution Committee presided. The first paper presented was entitled *The Petersen Earth Coil*, by R. N. Conwell and R. D. Evans, read by Mr. Conwell. This was discussed by W. W. Lewis, Carl Hering, C. L. Fortescue, H. M. Trueblood and L. P. Ferris.

Then followed the paper on *The Effects of Moisture on the Thermal Conductivity of Soils*, by G. B. Shanklin. This was discussed by D. W. Roper, R. W. Atkinson, W. A. Del Mar, G. E. Luke and C. J. Fechheimer. Next was the paper entitled *Five Hundred Tests on the Dielectric Strength of Oil*, by J. L. R. Hayden and W. N. Eddy, read by Mr. Hayden, and discussed by C. E. Skinner, F. M. Farmer, Jr., F. W. Peek, John B. Whitehead, Delafield DuBois, C. P. Steinmetz and written discussion by A. B. Hendricks, Jr., read by F. F. Brand.

The last paper of the session was that entitled *An Analytical Investigation of the Causes of Flashing of Synchronous Converters*, by E. B. Shand. This was discussed by J. L. Burnham, J. J. Linebaugh, H. M. Trueblood and F. C. Hanker, followed by closures by the authors.

Thursday Afternoon

The Thursday afternoon session was called to order by President McClellan, and H. R. Woodrow, Chairman of the Protective Devices Committee, occupied the chair during the session. The first paper presented was that on *The Use of Superimposed Imaginary E. M. Fs., Currents and Fluxes in the Solution of Alternating-Current Problems*, by V. Karapetoff. This was discussed by R. E. Doherty, Comfort A. Adams, Joseph Slepian, P. Trombetta and written discussion by W. V. Lyon. The next item was *Questions on the Economic Value of the Overhead Grounded Wire*, by E. E. F. Creighton. This was discussed by W. W. Lewis, C. L. Fortescue, E. P. Peck, Harry Barker, C. P. Steinmetz and written discussion by William S. Jones.

Next followed the paper on *Wave Form and Amplification of Corona Discharge*, by J. B. Whitehead and N. Inouye, presented by Dr. Whitehead. This paper was discussed by J. H. Morecroft, G. D. Robinson. The final paper of this session was entitled *Prevention of Transient Voltage in Windings*, by J. Murray Weed, and discussed by M. E. Skinner, F. F. Brand, H. O. Stephens, L. F. Blume, C. L. Fortescue, J. F. Peters, F. W. Peek and P. Trombetta. The discussions were followed by closure of the author.

Thursday Evening

At the Thursday evening session occurred the presentation of the Edison Medal to Cummings C. Chesney, notice of which appears elsewhere. This was followed by an address on Colloids by Dr. W. D. Bancroft.

Friday Morning

At the Friday morning session at which C. E. Skinner acted as Chairman, the first paper was entitled *Heating of Railway Motors in Service and on Test Floor Runs*, by G. E. Luke, and was discussed by M. R. Hanna, C. J. Fechheimer, F. W. Peters and A. C. Lanier. Next came the paper on *The "Indumor,"* by V. Karapetoff, which was discussed by C. W. Bates, E. E. F. Creighton, H. M. Hobart, E. G. Merrick, P. Trombetta and Lawrence E. Widmark. These discussions were followed by closures by the authors.

The following papers were read by title only: *Skin Effect and Proximity Effect in Tubular Conductors*, by Herbert Bristol Dwight, *Heat Losses in Stranded Armature Conductors*, by Waldo V. Lyon, *Current Locus of Single-Phase Induction Motors*, by J. K. Kostko and *Polyphase Commutator Machines*, by A. B. Field.

These were discussed by V. Karapetoff, E. W. Davis and A. S. Dana; also a written discussion by M. S. Vallarta. Mr. Dwight closed the discussion on his paper. The meeting then adjourned.

Friday Afternoon

Much interest was manifested in the various inspection trips that were scheduled for Friday afternoon, and about 300 members registered to visit the plants which were opened for inspection to members and guests of the Convention. These plants were as follows:

Famous Players—Lasky Corp. Studio and Laboratories, Astoria, L. I.

The New York Telephone Company, 24 Walker Street.

United Electric Light & Power Co., New Hell Gate Station.

Bell System Research Laboratories, 463 West Street.

Radio Corporation of America, Port Jefferson, Long Island.

New York Edison Company, Waterside power stations, East 38th-40th Streets and First Avenue; substation, 115-117 West 39th Street.

Brooklyn Edison Company, Gold Street Station, foot of Gold Street, Brooklyn.

United Electric Light and Power Co., power station at 201st Street and Harlem River; 97th St. substation, 97th St. between Columbus and Amsterdam Avenues.

Interborough Rapid Transit Co., 59th Street power station, 600 West 59th Street, New York; 74th Street, power station, 74th Street and East River, New York; substation No. 42, 57th Street and Third Avenue.

Public Service Electric Company, Essex power station, Newark, N. J.

Electrical Testing Laboratories, 80th Street and East End Avenue.

DINNER DANCE

Friday Evening

The dinner-dance, which has come to be a regular feature of the Midwinter Convention, was held at the Hotel Astor, New York, on Friday evening and was attended by 400 guests. An informal reception preceded the dinner after which dancing was enjoyed by all until a late hour.

Presentation of the Edison Medal to C. C. Chesney

An interesting and enjoyable feature of the Midwinter Convention was the presentation of the Edison Medal to Mr. C. C. Chesney on the evening of February 16th. The meeting was called to order by President McClellan. After a few words of welcome he called upon Prof. C. A. Adams who in a brief address explained the origin of the Edison Medal and the method of its award.

Address of W. B. Jackson

The Chairman then called on Mr. William B. Jackson, who gave a very interesting account of Mr. Chesney's life beginning with his student days at Pennsylvania State College, where he was prominent not only for his scholarship but as a leader in baseball and athletics. Mr. Jackson was associated with the medalist in the electrical works at Pittsfield, Mass., which were established by Mr. Chesney, William Stanley and John F. Kelly, and was therefore well acquainted with his pioneer work in the field of alternating-current development, the foundation of Mr. Chesney's later achievements in alternating-current transmission. The speaker narrated many interesting stories and intimate details of Mr. Chesney's early work and ascribed much of his success to his untiring industry and his characteristic perseverance in overcoming all obstacles and apparent impossibilities in an almost virgin field of endeavor.

The medal and diploma of award were then presented to Mr. Chesney by President McClellan.

Address of Mr. Chesney

In responding, Mr. Chesney spoke in part as follows:

The honor conferred on me in the award of the Edison Medal I accept with the deepest appreciation, for I am not unmindful of the fact that to have one's name added to the list of distinguished recipients is an honor above price, and indeed it would be an affectation on my part not to say that this is a proud moment in my life.

My activities in the electrical engineering field began with my employment by the late William Stanley, whom I first met in Great Barrington, Massachusetts, on the third of November 1888, two years after I had left State College. On my arrival in Great Barrington I reported at the Laboratory, and found Mr. Stanley engaged in repairing the commutator on his self-regulating alternator which had failed him the night before. The success of the series of experiments with alternate currents which he had carried on in Great Barrington two years before had given him the greatest confidence and enthusiasm in the possibilities of the alternating-current system, and of the transformer in particular, and he was anxious to the last degree to carry on their further development. He had at that time the full conception of the alternating-current station idea of manufacturing power—that is, to manufacture power in large volume at some suitable location, transmit and distribute it to points of consumption by the use of alternate currents.

I would be indeed derelict if I did not state tonight that it was Mr. Stanley's personal encouragement and enthusiasm during those early days, as well as his belief and vision of the future domain of electricity which turned me from the special study and practise of chemistry to the field of electrical engineering, and which has influenced me most in determining the course that I have subsequently followed in that field.

My first stay in Great Barrington and the Berkshire Hills was to be short lived, too short for my liking. For in the early summer of 1889 Mr. Stanley, at Mr. George Westinghouse's request, moved his laboratory to the plant of the U. S. Electric Lighting Company, at Newark, New Jersey. This company a few months previously had been purchased by the Westinghouse Electric & Manufacturing Company and a reorganization was taking place. With Mr. Stanley went the principal members of his Great Barrington staff. In Newark, in addition to the problems studied at Great Barrington, the study of the design of direct-current generators and motors was taken up by the Laboratory staff, and as part of my routine duties I designed a new line of d-c. generators and motors for isolated power and lighting purposes. It was my first accomplishment in the designing of dynamo-electric machines. These machines were immediately manufactured and sold by the U. S. Company.

The summer of 1890 was an eventful one in the commercial world. Business conditions demanded retrenchments on the part of the company. Reductions in the expenditures for development and experimental work, as is usual at such times, were ordered.

The outcome as far as I was concerned was altogether unexpected. In a few days after our excitement had subsided Stanley suggested that we leave the Westinghouse Company, go to Pittsfield and organize a company to manufacture transformers. The alternating-current field as a whole was new and undeveloped, the possibilities wonderful. Its complex and formidable problems then as now appealed to the imagination of the mathematician and mechanic. My early figures showed me that it was possible to produce economically a transformer much larger in capacity, of better efficiency and regulation, than any transformer that had yet been commercially offered. I, therefore, with much enthusiasm, but with some regrets it is true, decided to *take a chance* and went to Pittsfield with Mr. Stanley on November 1, 1890.

The manufacturing organizations of the new company were pushed forward with the vigor that the conditions demanded and warranted. The first transformers were shipped April 1, 1891, three months after the company was organized—a feat in which I have always taken great personal pride. To equip a factory for manufacturing any piece of electrical apparatus with the necessary machinery, organize the working force, design, build and ship a successful device all in three months, I know from my later years of experience was no mean engineering accomplishment from the standpoint of speed and quality. The commercial success of these transformers was immediate and the factory which was believed to be too large for the purpose was within a few months filled to its utmost capacity.

Mr. Chesney then told of many new manufacturing details that were incorporated in these transformers which were used on single-phase, 133-cycle circuits with an economical radius of distribution of from two to three miles. It had become obvious, if the alternating-current system was to progress, that polyphase circuits of lower frequency must be adopted. He then described his company's next step in the production of two-phase generators.

At this period of the art—1892 to 1894—the Stanley Electric Manufacturing Company introduced its novel polyphase alternator with its stationary armature, built for either 66 or 133 cycles and for any voltage up to and including 12,000 volts. The first of these alternators were built for 133 cycles and two-phase, and were early fitted with devices for varying independently the e. m. f. of each phase. They therefore could be used economically for single-phase as well as two-phase operation without appreciable reduction of output. A number of these high-frequency alternators was installed at this time in existing stations, operating during the day at two-phase, supplying electric light and power, and operating at single-phase at night during period of heavy lighting loads.

The first commercial use, however, of these alternators and transformers for the long-distance transmission of power was made in the village of Housatonic, Massachusetts. The Monument Mills operated large cotton mills in this village and owned a water power privilege on the Housatonic River located a mile and one-half north of its mills. A contract was given to the Stanley Electric Manufacturing Company for the complete electrical equipment of the mills.

The plant was put in operation in 1893, although not in daily operation until 1894. It was, therefore, the first commercial polyphase plant installed in this country for the transmission and distribution of polyphase currents for electric light and power. The alternators and pole line continued to be operated daily for more than twenty years and until they were replaced by those of larger capacity.

Based on the experience gained at Housatonic the important installation of the Montmorency Power Co. at the Falls of Montmorency, Quebec, Canada, was engineered for larger machines and higher voltages. The machines were of 600-kw. capacity and the operating potential 6000 volts. The frequency and phase adopted were the same as those which had proved satisfactory at Housatonic. This plant was put in operation in April 1895, and delivered two-phase currents for the entire requirements of the City of Quebec for electric light and power. It is worth stating that the alternators, from the date of their installation, were operated in parallel and that static condensers were first used extensively by the Montmorency Company on its circuits in Quebec to correct the low power factor caused by the use of induction motors.

Simultaneously with the development of the high-voltage alternator was carried on the development of the transformers for even higher voltages, producing in the late nineties transformers for 50,000 to 60,000 volts operation.

I wish to emphasize the fact that the changes introduced into the art during the early nineties of the last century by the engineers of that period have placed the whole structure of the electric art of to-day, as applied to light and power, firmly on the use of alternating currents.

These contributions by practical engineering to the world's affairs have been progressive in character, and were directed toward the one utlimate purpose of all science and engineering, the improvement in human conditions and an endeavor to bring into the world an era of more gracious living.

American Engineering Standards Committee

CONFERENCE ON CROSSING SPECIFICATIONS

At the request of the American Electric Railway Association, a conference has been called for March 2nd by the American Engineering Standards Committee, to decide whether there shall be uniform specifications for the crossing of overhead wires, and to dispose, if possible, of certain differences of opinion in regard to those parts of the National Electrical Safety Code which deal with overhead lines. It will be remembered that the code has been submitted to the American Engineering Standards Committee for approval.

FACTORY LIGHTING CODE

The Code of Lighting for factory mills and other work places, based upon earlier codes issued by the Illuminating Engineering Society and recently revised by a sectional committee under the sponsorship of this society has been officially approved as American Standard by the American Engineering Standards Committee.

The code is very brief, consisting of a few rules covering the minimum requirements, from the point of view of safety, for the illumination of traverse spaces during the time of use, methods for the avoidance of glare, and for exit and emergency lighting. Supplementary to the code are numerous suggestions relative to illumination values considered desirable for different classes of work and an outline of the advantages of good lighting.

OFFICERS ELECTED

At the adjourned annual meeting of the American Engineering Standards Committee held in New York on February 9th, Mr. Albert W. Whitney, a representative of the National Safety Council, was elected chairman, and Mr. George C. Stone, a representative of the American Institute of Mining and Metallurgical Engineers, was reelected vice-chairman. Mr. A. A. Stevenson, the retiring chairman, is a representative of the American Society for Testing Materials. The following were elected to represent the respective member-bodies on the Executive Committee:

Martin Schreiber	American Electric Railway Association
Sullivan W. Jones	American Institute of Architects
C. E. Skinner	American Institute of Electrical Engineers
E. A. Frink	American Railway Association (Engineering Division)
. . . .	American Society of Civil Engineers
Eugene C. Peck	American Society of Mechanical Engineers
John A. Capp	American Society for Testing Materials
. . . .	Association of American Steel Manufacturers
A. H. Moore	Electrical Manufacturers Council
N. A. Carle	Electric Light & Power Group
Dana Pierce	Fire Protection Group
A. Cressy Morrison	Gas Group
Coker F. Clarkson	Society of Automotive Engineers
Thos. H. MacDonald	U. S. Department of Agriculture
G. K. Burgess	U. S. Department of Commerce
O. P. Hood	U. S. Department of Interior
Francis J. Cleary	U. S. Navy Department
Beverly C. Dunn	U. S. War Department

NEW MEMBER-BODIES

Beginning with 1922, the American Railway Association (Engineering Division) and the Association of American Steel Manufacturers became member-bodies of the American Engineering Standards Committee. This brings the total number of national organizations represented upon the American Engineering Standards Committee up to twenty-eight, and of representatives to fifty-two.

INSULATED WIRE AND CABLE STANDARDIZATION

Insulated wires and cables constitute the biggest single item of manufactured electrical devices and machinery, their value being about 17 per cent of the total value of all such equipment.

Many engineering societies and commercial organizations have issued standard specifications for them which have come into very general use. All of these specifications, however, are made to apply to specific industrial uses and little has been done to coordinate them.

The first step toward this was taken last winter when the following ten engineering societies and other public organizations agreed to act as Sponsors, under the auspices of the American Engineering Standards Committee, for a comprehensive standardization of electric wires and cables for other than telephone and telegraph use:

American Electric Railway Association
American Institute of Electrical Engineers
American Railway Engineering Association
American Society for Testing Materials
Associated Manufacturers of Electrical Supplies
Association of Edison Illuminating Companies
Association of Railway Electrical Engineers
National Board of Fire Underwriters
National Electric Light Association
National Fire Protection Association

These organizations enlisted the cooperation of several others, and created a comprehensive group of committees to handle the work. The other cooperating organizations are:

Associated Bell Telephone Companies
Electric Power Club
Society of Automotive Engineers
U. S. Dept. of Commerce
U. S. Dept. of Navy
U. S. Dept. of War

The first meeting of the Sectional Committee was held on December 6, 1921. At this meeting, a formal plan of organization and procedure was adopted, officers elected, and the work definitely launched.

There are twelve technical committees to which specific phases of the work have been assigned. Like the Sectional Committee itself they are organized under the representational plan; that is, they are made up of representatives designated by the various organizations concerned in the particular subject with which each committee deals. These committees with their chairmen are as follows:

Definitions	W. A. Del Mar
Copper Conductors	J. A. Capp
Stranding	H. A. Morss
Rubber Insulation	F. M. Farmer
Impregnated Paper Insulation	D. W. Roper
Varnished Cloth Insulation	L. L. Elden
Magnet Wire	R. W. Longley
Fibrous Coverings	C. B. Martin
Metallic Coverings	W. I. Middleton
Standard Make Ups	C. A. Greenidge
Export	W. S. Clark
Weatherproof, Heat Resisting and Similar Materials.	. . . .

The officers of the Sectional Committee and other members of the Executive Committee are: Chairman, W. A. Del Mar; vice-chairman, E. B. Meyer; secretary, F. J. White; F. M. Farmer, Dean Harvey, E. B. Katte and Dana Pierce.

The task before this Sectional Committee is one of the largest yet undertaken under the auspices of the American Engineering Standards Committee. The total number of engineers participating in the work is over one hundred and thirty, and the list includes most of the men who have achieved distinction in the field of wire and cable engineering.

INTERNATIONAL COOPERATION IN STANDARDS

The American Engineering Standards Committee has just completed arrangements by which cooperation with the standardizing bodies in other countries will be made more effective. In doing this it has followed out the recommendations of the Unofficial Conference of the Secretaries of the National Standardizing Bodies held in London in April 1921.

In order that all standards shall be available to the industries of the various countries, it is planned that each national body will sell the approved standards of the other bodies. The American Engineering Standards Committee (29 West 39th St., New York City) has available the publications of the standardizing bodies in Austria, Belgium, Canada, France, Germany, Great Britain, Holland, Sweden and Switzerland.

RECENT FOREIGN ENGINEERING STANDARDS

Following are some engineering standards of interest to electrical engineers, issued in 1921 by foreign national standardizing bodies, which have been received by the American Engineering Standards Committee:

British Engineering Standards Association
- No. 77 Electrical Pressures for New Systems and Installations
- No. 91 Electric Cable Soldering Sockets
- No. 109 Air-Break Knife Switches and Laminated Brush Switches for Pressures not exceeding 660 volts
- No. 110 Air-Break Circuit Breakers for Pressures not exceeding 600 volts
- No. 133 Normal Type Vacuum Tungsten Filament Electric Lamps
- No. 139 Red Fir Wood Poles for Telegraph and Telephone Lines

Canadian Engineering Standards Association
- No. 2 Single-Phase Distribution Transformers, Standard Requirements for
- No. 3 Galvanized Telegraph and Telephone Wire

Association Belge de Standardization (Belgium)
- No. 7 Installation of Electrical Machinery and Transformers—Standard Rules (excluding traction material)

STANDARDIZING BODIES IN JAPAN AND NORWAY

Standardization work in Japan has recently been given a great impetus by the organization of the Japanese Engineering Standards Committee. The main function of this committee is to serve as a bureau for solving and initiating problems involving engineering standardization. The committee consists of 70 members presided over by the Minister of the Department of Agriculture and Commerce acting as president, and a vice-president, who is elected or appointed. The details of the work are handled by seven secretaries who are engineers of the government departments of Agriculture and Commerce, Communications, Railways, Military Engineers and Naval Engineers. The work is being pushed with vigor, investigations already being under way on metals, woods, bricks, screws, electric wires and electric motors.

In Norway a national standardization committee has been organized by the Federation of Norwegian Industries. One of the first projects which is being taken up by the new committee after the necessary work on organizational problems, is the standardization of ship machinery and ship details.

There are now national standardizing bodies in the following fourteen countries: Austria, Belgium, Canada, Czechoslovakia, France, Germany, Great Britain, Holland, Italy, Japan, Norway, Sweden, Switzerland and the United States.

American Engineering Council

The Executive Board of the American Engineering Council will meet in Chicago, Friday, March 10th, at the headquarters of the Western Society of Engineers, Monadnock Block, at 9:30 a. m. President Cooley will preside. The Michigan Engineers Club of Chicago, an alumni association of the University of Michigan, will give a dinner the evening of March 10 at the City Club in honor of Dean Cooley and President Burton. The members of the Executive Board are to be guests of the Michigan Engineers Club at this dinner.

American Electrochemical Society

MEETING IN BALTIMORE, APRIL 27-29

The Spring Meeting of the American Electrochemical Society will be held in Baltimore, April 27-29. In one of the papers to be presented at the meeting Dr. Duncan MacRae of the Westinghouse Research Laboratory describes a new method for determining the pressure in a tungsten vacuum lamp. The principle is simple and more accurate than the approximation that has heretofore been made by the well-known use of the induction coil. Dr. MacRae measures the pressures by a McLeod gage. The measurements on lamps immediately after the process of exhaust (before "flashing") and after "flashing," as well as on life-tested lamps, are given. The operation known as "flashing" consists in lighting the lamp during exhaust in the presence of phosphorus or other chemical substance.

Second Public Conference on Commercial Engineering

PITTSBURGH, MAY 1 AND 2, 1922

The United States Commissioner of Education is calling a second conference on commercial engineering, on behalf of a committee on commercial engineering appointed by him to investigate business training of engineers and engineering training for students of business, to be held May 1 and 2 at the Carnegie Institute of Technology in Pittsburgh. The conference will be open to the public.

Owing to the timeliness of the subject, the conference in Pittsburgh will even have greater national significance than the first public conference on the same question, which was held in Washington two and one-half years ago under the direction of this committee on commercial engineering. The committee, under the chairmanship of Dr. Glen Levin Swiggett of the Bureau of Education, is composed of deans of prominent schools of engineering and of commerce in our larger universities, and of engineers and business men who are nationally known for their interest in the reduction of the costs of production, distribution, transportation, etc., through better training in schools and colleges of the personnel of industry and commerce.

Engineers Club of Hampton Roads, Virginia

The Engineers Club of Hampton Roads, Virginia, has been organized and proposes to meet monthly at the Chamber of Commerce, Norfolk, Virginia. The officers are: President, W. A. Ludwick; first vice-president, J. C. Stephens; second vice-president, F. M. Weakley; secretary and treasurer, H. A. Brandt, P. O. Box 740, Portsmouth, Va.

Sheldon Memorial Foundation

The Sheldon Memorial Committee, organized some months ago under the chairmanship of T. Commerford Martin, to receive subscriptions toward a foundation in honor of the late Dr. Samuel Sheldon, Professor of Electrical Engineering and Physics at the Polytechnic Institute of Brooklyn, has turned over to the treasurer of the Polytechnic Institute the sum of $15,018, the amount so far paid in by more than 1000 subscribers. There are still a few unpaid subscriptions and it is hoped that enough further pledges will be secured to raise the fund to at least $20,000. Although the sum raised is hardly sufficient to really endow a laboratory, the Corporation of the Polytechnic Institute has ordered that the Electrical Measurements Laboratory be known hereafter as the Samuel Sheldon Memorial Laboratory of Electrical Measurements, and its members have collected among themselves an additional $1000 for immediate improvements and the installation of a memorial tablet. In this manner, the entire fund raised by the committee will be invested in the form of a trust and the income used per-

petually for the maintenance of the laboratory, which will thereby become one of the best laboratories of electrical measurements in the country.

Dr. Sheldon was professor of electrical engineering and physics at the Polytechnic Institute of Brooklyn from 1889 until the time of his death in 1920, and was well-known throughout the country as an educator, engineer and author. During the year 1906 to 1907 he served as president of the A. I. E. E., and at all times was ready to aid in the activities of this Institute as well as of other engineering societies to which he belonged. General sentiments of esteem and admiration toward Dr. Sheldon have been expressed to the Memorial Committee, and the loyalty of several hundred former students to his memory has also been evinced.

United Engineering Society

EXTRACTS FROM TREASURER'S REPORT FOR 1921

The report of the treasurer of United Engineering Society for the calendar year 1921 shows a balancing account on December 31, 1921, of $26,434.31, as compared with a balancing account on December 31, 1920, of $16,954.72. The cash on hand as of December 31, 1921, amounted to $14,219.35. Following is a statement of the treasurer's receipts and payments for the year:

RECEIPTS

Cash on hand January 1, 1921		$15,029.02
From Founder and Associate Societies for offices, storage, halls, telephone and miscellaneous	$98,666.45	
From societies not in building for halls and miscellaneous	17,530.79	
For Library, General Maintenance and Operation	25,291.61	
For Library Service Bureau	16,738.16	
For Library Recataloguing	12,291.53	
Income collected on Investments and Deposits of U. E. S.	12,116.83	
Income collected on Engineering Foundation investments	24,533.57	
Sale of Securities	27,874.38	
From A. I. E. E. for Building Addition	2,500.00	237,543.32
		$252,572.34

PAYMENTS

To Engineering Foundation		
Income from Investments less Collection charges	$24,258.31	
For Securities purchased	25,400.00	
" Building Operating expenses	101,370.21	
" Library	27,588.43	
" Library Service Bureau	15,755.41	
" Library Recataloguing	13,606.01	
" A. S. M. E. Note	2,500.00	
" A. S. M. E. Interest on note	206.20	
Collection, custodial and Adv. charges and exchanges	650.83	
For Engineering Council	14,500.00	
" Engineering Soc. Service Bureau	406.74	
" Permanent Improvement charged to capital	1,786.36	
" Renewals in steam system charged to Depreciation and Renewal Fund	9,395.91	
For American Delegation Dinner	805.10	
" Miscellaneous	123.48	
Grand total		$238.352.99
Cash on hand December 31, 1921		14,219.35
		$252.572.34

The assets and liabilities as of December 31, 1921, were as follows:

ASSETS

Property			$1,959,140.67
Land	$540,000.00		
Building	1,361,969.51		
Equipment	33,171.16		
Founders' Preliminary Expenses	24,000.00		
Investments Foundation			502,066.05
Library			93,351.25
Depreciation and Renewal			98,639.47
General Funds			10,000.00
Cash		10,477.25	
Special Cash Funds		50.00	
Due from Cleveland Trust Co.		99.16	
Cost of renewals paid from Operating Cash to be reimbursed from Depreciation and Renewal Fund Assets		1,698.47	
Accounts Receivable		8,835.98	
Accrued interest receivable on Library Endowment Investments		1,246.14	22,407.00
Deferred charges, prepaid insurance			4,230.31
			$2,689,834.75

LIABILITIES

Founders Equity in Property	$1,959,140.67
Engineering Foundation Reserve	502,066.25
Library Endowment Reserve	93,351.25
Depreciation and Renewal Reserve	98,639.47
General Reserve	10,000.00
Collection on account Osterberg Fund	91.50
Income from Engineering Foundation Investments collected and to be paid to Engineering Foundation Board	58.60
Deferred credit—unexpended balance in American Delegation Dinner Account	52.90
Balance December 31, 1921	26,434.31
	$2,689,834.75

Engineering Foundation

NEW PUBLICATION TO BE ISSUED

Engineering Foundation has on the press a report of its seventh year of activities in research connected with various branches of engineering. The book will contain also an abridged report of the extensive investigation of the fatigue phenomena of metals, made possible by a large contribution from the Foundation. This investigation was conducted at the Engineering Experiment Station of the University of Illinois. In this publication the Foundation Board gives its supporting societies information about work done and projects under consideration. Members desiring to obtain a copy of this report when issued should write promptly to the office of Engineering Foundation, in Engineering Societies Building, 29 West 39th Street, New York.

SEVENTH ANNUAL BOARD MEETING

The seventh annual meeting of Engineering Foundation Board was held in the Engineering Societies Building, New York, on February 9, 1922. There were present Charles F. Rand, chairman, Edward Dean Adams, John H. Barr, George M. Basford, J. Vipond Davies, Bancroft Gherardi, W. F. M. Goss, D. S. Jacobus, F. B. Jewett, Edwin Ludlow, George H. Pegram, H. Hobart Porter, Arthur L. Walker; Joseph Struthers, treasurer; Alfred D. Flinn, secretary; C. B. LePage, representing Calvin W. Rice, secretary, A. S. M. E. Regrets were received from Ambrose Swasey, I. E. Moultrop, Robert M. Raymond, E. Wilbur Rice, Jr., Elmer A. Sperry, H. M. Boylston and S. H. Woodard.

The chairman read the annual report, and announced that a fuller report had been prepared for publication, together with an abridged report on the Fatigue of Metals research (see notice above). Then followed reports by representatives of the Foundation on other organizations and reports of committees on research work. General progress was indicated. Results of the investigations are published by the Foundation at various times, and notices of them will appear in the JOURNAL.

A suggestion for a department to encourage research and invention was presented in the form of a communication dated February 6, from Dr. Byron E. Eldred. This had previously been mailed to members of the Board. The proposal is summarized as follows:

1. Establish a department for assisting inventors by,
   - *a.* Giving information, advice and financial assistance;
   - *b.* Examining suggestions and inventions offered;
   - *c.* Developing ideas believed to be of value;
   - *d.* Securing patents for, and commercializing, inventions which have passed thorough examination.

2. Engage as director of the proposed department, an engineer experienced in development of inventions and in patent practise.
3. Provide a small technical and clerical staff for the director.
4. Create a board of review, of engineers, scientists and patent attorneys of eminent standing.
5. Create a board on commercialization of inventions, to be composed of business men, industrialists and bankers.
6. Make this service known, and stimulate research and invention, by lectures of the director before public bodies and college classes, and by personal contacts with men of affairs.
7. Obtain a large endowment fund, the income of which would support the work and which would be increased by participation in the emoluments of successful inventions.

A committee consisting of Bancroft Gherardi, chairman, H. Hobart Porter, Edward Dean Adams, and John H. Barr was appointed to examine and report upon the suggestion.

The following officers for the year ending at the annual meeting in 1923 were elected as recommended by the Nominating Committee: chairman, Charles F. Rand; first vice-chairman, Edward Dean Adams; second vice-chairman, F. B. Jewett; treasurer, Joseph Struthers; assistant treasurer, Henry A. Lardner; secretary, Alfred D. Flinn; assistant secretary, by reciprocal arrangement, the permanent secretary of National Research Council, Vernon Kellogg; additional members of the Executive Committee, George H. Pegram and H. Hobart Porter.

The Board then adjourned to Thursday, May 11, 1922.

PERSONAL MENTION

W. G. Vincent, Jr., of the Pacific Gas & Electric Company, San Francisco, has been elected a vice-president of that company.

John M. Nairn has started into business for himself under the name of Superior Electrical Company, Jersey City, N. J.

R. W. Shoemaker has become connected with The Turlock Irrigation District, Turlock, Cal., as electrical engineer.

Francis H. Achard has resigned his position with The Angus Company, Ltd., Calcutta, India, and is returning to this country. His home is in Brookline, Mass.

Francis M. Hartmann, professor of electrical and mechanical engineering, Cooper Union, New York City, has been elected first dean of the Day Technical School of Cooper Union. Prof. Hartmann is a Fellow of the Institute.

Kendall Buck has left the Puget Sound Power & Light Company at Dieringer, Wash., and will establish an electrical department in two stores of the Standard Paint Products Company in Los Angeles.

Clinton W. Hough, who returned to this country last summer from London, where he was director with J. G. White & Company Ltd., is at present locted with The North American Company, New York City.

Geo. T. Southgate, formerly research engineer with the American Cyanamid Company, Brewster, Fla., is now located with the Bureau of Soils, Department of Agriculture, Washington, D. C.

Milton Oertel, until recently with the Raritan Copper Works, Perth Amboy, N. J. has accepted the position of foreman of the motor department of the National Electric Company, Passaic, N. J.

Henry R. Stevens will be located for some time in Nagoya, Japan, with the Daido Electric Power Company. He will act as construction engineer representing Thebo, Starr and Anderton, consulting engineers of San Francisco.

D. W. Blakeslee, of the Jones & Laughlin Steel Company, Pittsburgh, is on leave of absence from that company and is teaching electrical engineering in Yale University during the school year.

E. B. Merriam, of the General Electric Company, has been appointed executive engineer of the switchboard department, to direct and coordinate the engineering activities of this department at Schenectady, Philadelphia, and Baltimore.

Ray H. Angove has become publicity director of The Wisconsin Telephone Company, Milwaukee. He was formerly in the advertising department of the Cutler-Hammer Manufacturing Company.

J. J. Thomason, for the past three years assistant engineer of the Southwestern Gas and Electric Company of Texarkana, Ark.-Tex., is now located with Fuller and Beard, consulting engineers of St. Louis.

Ivar Herlitz, fellow of the American Scandinavian Foundation, formerly with the Southern Sierras Power Company, Riverside, Cal., is studying high-voltage transmission problems in California on a research scholarship from the Swedish Academy of Engineering Science.

Paul L. Battey has announced the opening of a consulting engineering office at 123 West Madison Street, Chicago. Mr Battey was formerly vice-president of the Arnold Company, Chicago, and for many years chief engineer in charge of all industrial operation. Recently he has acted as consulting engineer for the Willys Corporation, Elizabeth, N. J.

Walter D'Arcy Ryan of the General Electric Company, Schenectady, and well-known for his illuminating design and installation in connection with the Panama-Pacific Exposition, returned to this country from Rio de Janeiro on January 24th. Mr. Ryan had been in Rio to plan and design the complete illuminating features of the Brazilian Exposition which opens in Rio on September 7th.

Peter Junkersfeld of the newly organized firm of McClellan and Junkersfeld and until recently engineering manager for Stone & Webster, Boston, was from 1895 to 1919 associated with the Chicago Edison Company and its successor the Commonwealth Edison Company, of which he became assistant vice-president, supervising contracting, engineering, construction and operation work. In June 1917 Mr. Junkersfeld entered the U. S. Army and was successively, Major, Lieut. Colonel and Colonel.

Wm. McClellan, President of the Institute, has announced the incorporation of the firm of McClellan and Junkersfeld, with temporary offices at 141 Broadway, New York City. The work of the new organization will be on power plants, transmission systems, water powers, electrification of railroads and general industrial and utility engineering and construction. Dr. McClellan's early experience was with the Philadelphia Rapid Transit Co. For several years he was with Westinghouse, Church, Kerr & Co., participating in the Pennsylvania Terminal electrification. Later he was electrical engineer of the Second District Public Service Commission of New York. For eight years he was with the Cleveland Electric Illuminating Company, two years as its vice-president.

N. A. Carle, formerly chief engineer of the Public Service Electric Company, Newark, N. J., has just become vice-president and general manager of the Public Service Production Company, engineers and constructors, with offices at 80 Park Place, Newark. This company is a newly incorporated subsidiary of the Public Service Corporation of N. J. and will engage in designing, construction and maintenance of all kinds of public utilities and industrial plants, electrification of steam railroad properties, repair of equipment, reorganization of utility or industrial plants, paving of roads, efficiency tests and reports, valuation studies and financing. E. B. Meyer, formerly assistant chief engineer of the Public Service Electric Company, has been appointed chief engineer of the Public Service Production Company.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

EXTRACTS FROM ANNUAL REPORT FOR 1921

While the achievements in connection with the Engineering Societies Library during the year 1921 have not been spectacular they have been substantial and important. The collection has increased in size, the revision of the catalog has been prosecuted with vigor, and large numbers of volumes that were practically inaccessible have been arranged so that they can be used. Much work has been done in improving the shelf arrangement so that readers may work easily. The service to members has, it is believed, been better in quality than ever before.

Estimates of the library collection on December 31, 1921, show the following figures:

Volumes	118,980
Pamphlets	34,091
Maps and Plans	555
Manuscript Biliographies	3,904
Total	157,530

The income and expenses of the Library during 1921 were as follows:

General Operation

INCOME, 1921

Founder Societies, Regular Appropriation		$22,000.02
Founder Societies, Special Appropriation		3,750.00
Endowment Fund Income		4,914.70
Mailloux Fund Income		467.61
		$31,132.33

EXPENSES 1921

Salaries	$18,638.16	
Books and Binding	6,859.94	
Supplies	2,177.84	
Equipment	350.10	
	$28,026.04	
Restoration of Petty Cash	25.00	$28,001.04
Operating Surplus, Dec. 31, 1921		$ 3,131.29
Operating Deficit, Dec. 31, 1920		3,191.92
Deficit Dec. 31, 1921 (adv. by U. E. S.)		$ 60.63

Recataloging

INCOME, 1921

Founder Societies Appropriations	$ 9,999.86
Carnegie Corporation Appropriations	2,500.00
	$12,449.86

EXPENSES, 1921

Salaries	$13,606.01
Operating Deficit Dec. 31, 1921	$ 1,106.15
Operating Deficit Dec. 31, 1920	1,950.46
Total Deficit (Adv. by U. E. S.)	$ 3,056.64

Service Bureau

REVENUE, 1921

Surplus Jan. 1, 1921	$ 710.27
Total Billed (Search Dept.)	8,868.18
Total Billed (Photoprint Dept.)	5,676.36
	$15,254.81

EXPENSES, 1921

Salaries, Searchers	$ 8,836.22	
Salaries, Photographers	3,567.16	
Supplies, Searchers	1,397.50	
Supplies, Photographic	1,954.53	
	$15,755.41	
Restoration of Petty Cash	25.00	$15,730.41
Operating Deficit, Dec. 31, 1921		475.60
Uncollectable Accounts Written Off		470.58
Deficit, Dec. 31, 1921		$ 946.18

The attendance during the year reached a total of 26,840 of which total 3894 represented evening attendance. There were made 332 searches in all branches of engineering, and the translations amounted to 289,000 words.

The following table compares the income and expenditures of the last two years:

	1920		1921	
	Income	Expenses	Income	Expenses
General Maintenance	$25,922.87	$29,114.79	$31,132.32	$31,192.92
Recataloging	11,472.01	13,422.50	12,499.86	15,556.50
Service Bureau	21,908.76	22,086.88	15,254.81	16,676.59

BOOK NOTICES (JAN. 1-31, 1922)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

THEORY OF THE INDUCTION COIL.

By E. Taylor-Jones. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. 217 pp., illus., 8 x 5 in., cloth. $3.50.

Until recently there has been much divergence of view as to the manner in which the high potential is generated at the secondary terminals of an induction coil when the primary current is interrupted, and it cannot be said even now that opinion on the subject is quite undivided. In this book an account is given of a theory of the action of induction coils first put forward by the author in 1909. The theory was originally intended to apply only to the case of an air-core induction coil having a condenser connected with its secondary terminals. Subsequent investigations have shown that it is also applicable to an ordinary induction coil.

PROTECTIVE RELAYS.

By Victor H. Todd. First edition. N. Y. and Lond. McGraw-Hill Book Co., Inc., 1922. 274 pp., illus., diagrs., 8 x 6 in., cloth. $2.50.

This book attempts to cover the subject from first principles to the protection of high-tension networks, in a manner suited to the needs of operators and testers with a fair knowledge of electricity, and also of designers.

Handbuch der Drahtlosen Telegraphie und Telephonie.

By Eugen Nesper. Berlin, Julius Springer, 1921. 2 vol., illus., diagrs., 10 x 7 in., cloth.

Dr. Nesper's book on radio communication attempts an exhaustive survey of the subject from a modern point of view and from every aspect. It is apparently more extensive than any previous work on the subject. It has been planned for easy reference, the material having been so arranged that each chapter is a complete account of a certain topic, so that reference to other chapters, or systematic reading of the whole work, can be avoided.

The theory of radio communication, its history, uses, the measuring and detecting instruments, the physical phenomena in quasi-stationary circuits, coupling, damping, radiating, the technique and apparatus of high-frequency measurements are described in volume one. Volume two describes typica radio stations for different purposes and their apparatus, the uses of radio communication in railroading and radio telephony. It also includes a valuable bibliography of the important books and articles. Good indexes are provided.

Hydraulics and its Applications.

By A. H. Gibson. New edition, revised and enlarged. N. Y. D. Van Nostrand Co., 1921. 813 pp., illus., diagrs., 9 x 6 in., cloth. $6.00.

This book opens with a description of the physical properties of water, followed by a brief treatment of the fundamentals of hydrostatics. The science of hydraulics is then presented, first theoretically and then with regard to its application to the design of hydraulic machinery. The work is written primarily for students, but the author hopes it may also prove of value to those actively engaged in the practise of hydraulic engineering.

This edition has been practically rewritten, with considerable additions and much rearrangement of the material.

Die Wasserversorgung der Stadte.

By O. Smreker. Funfte auflage. Leipzig, Wilhelm Engelmann, 1914. (Handbuch der Ingenieurwissenschaften. Teil 3. Der Wasserbau, Bd. 3). 522 pp., illus., diagrs., tables, 10 x 7 in., cloth. 57 Mk.

This work forms the third of the twelve volumes upon hydraulic engineering which constitute the third section of the Handbuch der Ingenieurwissenschaften, and is concerned with municipal water supplies. The present edition has been thoroughly revised, both with respect to arrangement and contents.

The arrangement follows the course of operations used in securing a water supply, discussing first the preliminary studies of the amount, quality and occurrence of the available sources, then the design of the plant in general. Succeeding chapters discuss the winning and purification of water, pumping and conveying, and the operation of water-works. Attention is directed toward general principles, rather than to the details of specific installations.

Short Course in the Testing of Electrical Machinery.

By J. H. Morecroft and F. W. Hehre. Fourth edition, revised and enlarged. N. Y., Van Nostrand Co., 1921. 220 pp., diagrs., 9 x 6 in., cloth. $3.00.

All students of engineering at Columbia University are required to take courses in testing direct and alternating-current machinery. These notes are prepared to meet the needs of students in mining, mechanical and civil engineering, who have not studied the theory of electrical machinery, and hence need a brief summary of it as preparation for the laboratory work.

Besides giving specific directions for the tests, a brief analysis of the characteristics of the machines is given. The new edition includes new material on batteries, illumination, measurement of electrical energy and other subjects of interest to engineers generally.

Atomic Theories.

By F. H. Loring. N. Y., E. P. Dutton and Co., 1921. 218 pp., illus., 9 x 6 in., cloth. $5.00.

The leading facts and theories relating to the atom, particularly those which, owing to their newness, have not yet been treated at any length in text-books, are brought together in one volume for the convenience of students and investigators. The book covers a wide range of subjects. These include the quantum theory, Sir J. J. Thomson's recent views of mass, matter and radiation, the Bohr theory, the octet theory, isotopes, the Brownian movement, ionisation, potentials, solar phenomena and other subjects. References are given throughout, which enable the reader to follow any subject of special interest.

La Matiere et L'Energie Selon la Theorie de la Relativite et la Theorie des Quanta.

By Louis Rougier. Nouvelle édition, revue et augmentee. Paris, Gauthier-Villars et Cie, 1921. 112 pp., 10 x 7 in., paper. 9.50 fr.

This book calls attention to the most paradoxical and least discussed consequence of the principle of relativity, that which attributes mass, weight and structure to energy. What we call matter thus becomes only a particular case of energy. The old duality of ponderable and imponde able makes way for that of the electro-magnetic field of *energy*, of which radiation and matter are simple modalities, and of the field of gravitation or *space* as defined by Einstein. Professor Rougier presents these theories in this work.

Physique Elementaire et Theories Modernes.

By J. Villey. Pt. 1. Molécules et atomes. Paris, Gauthier-Villars et Cie, 1921. 197 pp., 10 x 6 in., paper. 15 fr.

The author has prepared a work, less scholastic than usual text-books and more suited for reading, in which the essential phenomena of physics are set forth and explained by the most modern theories. Attention is especially directed to those phenomena which have received industrial application.

The work is intended for the general public desirous of information about the fundamentals of physics and modern theories, as well as for use as a text-book.

Descriptive Geometry.

By George Young and H. E. Baxter. N. Y., The Macmillan Co., 1921. 310 pp., diagrs., 8 x 5 in., cloth. $3.25.

Believing that the chief value of descriptive geometry lies in its imaginative quality, these authors present it so as to develop the imagination; and therefore they encourage intuitive rather than rigidly formal methods. The treatment has been kept purely abstract, in order to avoid the tendency of the subject to degenerate into practical rules and formulas; but introductory matter showing the relation of the principles under discussion to structural work is provided, and exercises to show the application of the abstract ideas to concrete, practical problems are included.

Industrial Fatigue and Efficiency.

By H. M. Vernon. Lond., George Routledge & Sons, Ltd.; N. Y., E. P. Dutton & Co., 1921. 264 pp., tables, 9 x 6 in., cloth. $5.00.

The author, who is an investigator for the Industrial Fatigue Research Board of Great Britain, presents a fairly complete account of our present knowledge concerning industrial fatigue and its influence on efficiency. The information adduced relates only to shop practise, as laboratory investigations have not, in the author's opinion, afforded much evidence of practical value.

Essentials of Industrial Costing.

By George S. Armstrong. N. Y., D. Appleton and Co., 1921. 297 pp., tables, forms, 9 x 6 in., cloth. $5.00.

Contents: Economic development and necessity of costing.—The purpose and function of costing.—The mechanism of costing.—Elements of costing and sources of costing data.—The costing of material.—The costing of labor.—The collection of expense in costing.—The costing of depreciation, interest, and power.—The distribution and application of expense in costing.—Final costing.—The connection of costing with the general books and the preparation of monthly statements therefrom.

As indicated by the contents, this book is concerned solely with the principles and methods by which the cost of production may be determined. It is based upon an extended experience in many different industries and represents the author's mature views. The book shows the purpose of costing, summarizes good practise and is a guide to the analysis necessary for the establishment of costing systems.

Construction, Cost Keeping and Management.

By Halbert Powers Gillette and Richard T. Dana. First dition. N. Y. and Lond. McGraw-Hill Book Co., Inc., 1922. 572 pp. forms 8 x 5 in., cloth. $5.00.

This book has been prepared in response to requests for a second edition of "Cost Keeping and Management Engineering." It contains nearly all the original material, supplemented by that developed in the last twelve years. It is intended to assist in reducing construction costs to the minimum, by explaining the rules of management and setting forth suitable methods of cost keeping, adapted to engineering construction.

Past Section and Branch Meetings

SECTION MEETINGS

Atlanta.—January 26, 1922, Chamber of Commerce Building. Subject: "The Manufacture of Wire and Cable." Speaker: Mr. F. T. White, of the Okonite Company, Passaic, N. J. The talk was illustrated by an interesting moving picture film of five reels. Attendance 50.

Baltimore.—January 20, 1922, Johns Hopkins University. Subject: "The Determination of the Physical Characteristics of Steel by Magnetic Analysis." Speaker: Prof. W. B. Kouwenhoven, of Johns Hopkins University. Mr. J. H. Davis, of the B. & O. Railroad, told of the work which he had done in attempting to control the tempering of the flat leaves of locomotive springs by a magnetic test. Messrs. E. D. Edmonston and Douglass Burnett of the Consolidated Gas, Electric Light & Power Company, also contributed to the discussion of Professor Kouwenhoven's paper. Refreshments were served. Attendance 60.

Boston.—January 24, 1922, Boston City Club. Subject: "Great Lakes, St. Lawrence Tide Water Project." Speaker: Mr. Henry deB. Parsons. Mr. Parsons considered chiefly the hydroelectric and civil engineering phases, after which Mr. W. L. Saunders, President of the Ingersoll-Rand Company, spoke on the commercial and transportation features. Attendance 200.

Chicago.—January 31, 1922, Fullerton Hall. Chicago Art Institute. Joint meeting with the Western Society of Engineers. Subject: "Radio Telephony and Telegraphy." Captain Ralph Brown, of the American Tel. & Tel. Company, gave a clear and interesting lecture on "Radio Telephony," illustrated by lantern slides. Mr. R. H. G. Mathews, Director of the Chicago Radio Laboratory, gave a practical demonstration of Radio Telephony and Telegraphy explaining the operations as he proceeded and reproducing the regular service from the Westinghouse Radiophone Studio. Attendance 500.

Cincinnati.—February 9, 1922, University of Cincinnati. Subject: "Combustion." Speaker: Mr. F. H. Daniels, of the Sanford Riley Stoker Company. A series of moving pictures was shown giving a very clear idea of what goes on inside of a furnace. These pictures were preceded by a number of lantern slides and explanations of just how these pictures were obtained, and the difficulties in taking them. Attendance 100.

Cleveland.—December 20, 1921, Electrical League Rooms. Joint meeting with Cleveland Radio Association. The Cleveland Radio Association provided an excellent radio entertainment. Radio Station 8-A C S broadcasted phonograph vocal and band music. Band music was furnished by Nela Park Band. Preceding the radio concert Mr. Poad of the Cleveland Radio Association addressed the meeting from the broadcasting station by radiophone. At the conclusion of the musical program the Chairman thanked the Cleveland Radio Association and the talent who furnished the music. These remarks were addressed to broadcasting station 8-A C S by means of a small radio telephone transmitter which was set up at the meeting. Mr. Hurd of Nela Park, who operated the receiving station at the meeting, briefly described the operation of the equipment. Attendance 135.

Connecticut.—January 13, 1922, Yale University, New Haven, Conn. Subject: "Radio Telephony." Speaker: Mr. Ralph Bown, of the American Tel. & Tel. Company, New York. The lecture covered the fundamental physical principles on which radio communication, especially telephony, rests and described the apparatus used in speed transmission. After the lecture the audience listened to vocal and piano selections sent out from the radio station of the F. M. Doolittle Company on Chapel Street. Attendance 175.

Denver.—January 14, 1922, Denver Tramway Auditorium. Subject: "The Human Voice and Its Electrical Transmission." Speaker: Mr. John Mills, of the Personnel Division of the Engineering Department of the Western Electric Company, New York. The talk was illustrated by motion pictures, lantern slides and experiments. Attendance 300.

Fort Wayne.—January 19, 1922, Home Telephone & Telegraph Company. Subject: "The Heart Throbs of a City." Speaker: Mr. E. L. Gaines, Traffic Manager, Home Telephone & Telegraph Company. After the talk the members were taken through the exchange in small groups and the details of operation explained. A light lunch was served by the Telephone Company. Attendance 50.

Indianapolis-Lafayette.—December 15, 1921. Subject: "General Theory, Performance and Characteristics of Induction Motors." Speaker: Mr. W. A. Black, Chief Engineer, Indianapolis Works of the Fairbanks-Morse Electrical Mfg. Company. Attendance 75.

January 19, 1922. Subject: "The Automobile Storage Battery; Its Theory and Operating Characteristics." Speaker: Mr. Harvey Mitchell Anthony, of Muncie, Ind. The lecture was demonstrated by many lantern slides which covered the construction of the modern storage cell, the manufacture, the factors determining its efficiency, capacity and maintenance. Attendance 72.

Lynn.—January 18, 1922. Subject: "The Use of Electrically Driven Appliances in Bone Surgery." Speaker: Dr. Fred H. Albee of New York. The lecture was illustrated by approximately fifty lantern slides and two reels of motion pictures. Attendance 200.

February 1, 1922, Lynn Classical High School Hall. Ladies' Night. Subject: "Natural Color Photography," (illustrated by lantern slides). Speaker: Professor Louis Derr of the Massachusetts Institute of Technology. Attendance 450.

February 8, 1922. G. E. Hall. Subject: "The Manufacture of Commercially Pure Iron and Special Steel Sheets." Speaker: Mr. T. W. Jenkins, of the American Rolling Mills Company, Middletown, Ohio. The lecture was illustrated by motion pictures. Attendance 250.

Minnesota.—January 26, 1922, Curtis Hotel, Minneapolis. Dinner Dance under the auspices of the Minnesota Section of the A. I. E. E. and the St. Paul and Minneapolis Sections of the A. S. M. E. Program: Toastmaster, Charles L. Pillsbury; "The American Institute," by Professor W. T. Ryan; "The American Society," by Hans J. Meyer; "Some Experiences Abroad," by Max Toltz. Attendance 103.

Panama.—January 22, 1922. Inspection trip through the Pacific Fortifications, conducted by Colonel Pullen, Engineer Corps, and Major L. H. Sanford, Engineer Corps. Attendance 69.

Philadelphia.—January 9, 1922, The Engineers Club, Philadelphia. Subject: "The Philadelphia-Pittsburgh Section of the Philadelphia-Chicago Cable." Speaker: Mr. J. J. Pilliod, of the American Telephone & Telegraph Company, New York. Preceding the meeting fifty-eight members and guests participated in a complimentary dinner to Mr. Pilliod. Attendance at meeting 214.

January 17, 1922, Bellevue-Stratford Hotel. Meeting under auspices of the Engineers Club of Philadelphia, and Philadelphia Sections of the A. I. E. E., A. S. C E., and A. S. M. E. Subjects: "Financing of Large Engineering Projects," by Mr. Philip Cabot, of Boston; "Engineering in Civilization," by Mr. John E. Zimmerman, of Philadelphia; "Engineering and Finance—An Opportunity for Close Cooperation," by Mr. Willis H. Booth, of New York; "American Finance," by Mr. George E. Roberts, of New York. Attendance 360.

Pittsburgh.—January 10, 1922, Chamber of Commerce Auditorium. Subject: "Flashing of Synchronous Converters." Speaker: Mr. E. B. Shand, of the Westinghouse Elec. & Mfg. Company. After the meeting the members were invited to remain for a social get-together. Messrs. J. W. McKelvie, baritone, and A. T. Weiblinger, pianist furnished a number of fine selections and led the crowd in singing. Attendance 235.

Pittsfield.—January 12, 1922, G. E. Auditorium. Subject: "Relativity." Speaker: Dr. C. P. Steinmetz. Third of a series of lectures by Dr. Steinmetz on this subject. Attendance 150.

January 19, 1922, G. E. Auditorium. Subject: "The Manufacture and Use of Die-Castings." Speaker: Mr. Charles Pack of the Doehler Die-Casting Company. Attendance 300.

February 4, 1922, Masonic Temple. Subject: "The Romance of Human Civilization" (illustrated with lantern slides). Speaker: Mr. B. R. Baumgardt. The lecture was preceded by a concert given by the Kilowatt Orchestra. Attendance 750.

Portland.—January 10, 1922, Benson Hotel. Subject: "A Geological Outline of Oregon, with Particular Reference to the Columbia River Gorge and Adjacent Region." Speaker: Mr. Ira A. Williams, Geologist, Oregon State Bureau of Mines. After the meeting an informal dance was enjoyed by all, and refreshments were served. Attendance 150.

February 2, 1922, University Club. Subject: "The Human Voice and Its Electrical Transmission." Speaker: Mr. John Mills of the Western Electric Company, N. Y. The lecture was accompanied by stereopticon and motion picture illustrations. Refreshments were served. Attendance 190.

Providence.—February 3, 1922, Providence Engineering Society Rooms. Subject: "Radio Telephony." Speaker: Mr. W. R. G. Baker, of the Radio Engineering Department of the General Electric Company. Before and after the lecture a demonstration of radio telephony was given, music and voice being received from the transmitting station at Brown University. A loud speaker was used as part of the receiving apparatus, thus making it possible for all those present to hear this practical demonstration. Attendance 145.

Rochester.—January 27, 1922, Chamber of Commerce. Joint meeting with Rochester Chamber of Commerce and Rochester Engineering Society. Subject: "The Superpower Survey." Speaker: Mr. W. S. Murray of New York. Attendance 200.

St. Louis.—January 25, 1922, Engineers Club. Subject: "Telephoning from Cuba to the Catalina Islands." Speaker: Mr. H. S. Osborne, of the American Telephone and Telegraph Company. Mr. Osborne went into details regarding the construction of the various links connecting Cuba and the Catalina Islands and dwelt in particular on certain phases which were of great interest to those in attendance. Attendance 65.

San Francisco.—January 20, 1922, Engineers Club. Subject: "Vacuum Tubes." Speaker: Dr. David L. Webster, of Stanford University. Dr. Webster had brought with him a number of tubes and devices with which he showed the evolution of vacuum tubes, and also some interesting experiments. Attendance 131.

Schenectady.—January 6, 1922, Edison Club Hall. Mr. David B. Rushmore presented a paper entitled "Energy," which was read by title only. Mr. Saul Dushman spoke on the "Structure of the Atom." Attendance 250.

January 20, 1922, Edison Club Hall. Subject: "U. S. Army Engineers and Industrial and Power Development." Speaker: Colonel J. Franklin Bell, U. S. A., Corps of Engineers, Pittsburgh, Pa. Attendance 92.

February 3, 1922, Edison Club Hall. Subject: "On the Frontiers of the Universe" (illustrated). Speaker: Mr. B. R. Baumgardt. Attendance 450.

Seattle.— January 30, 1922, Knights of Columbus Hall. Joint meeting with Seattle Section of Institute of Radio Engineers. Subject: "Human Voice and Its Electrical Transmission." Speaker: Mr. John Mills, of New York. The lecture was illustrated by lantern slides, motion pictures, oscillograph projections and special demonstrations. Attendance 232.

Spokane.—January 6, 1922, Davenport Hotel. Subject: "Tests on Constant Current Regulators for Series Street Lighting Systems." Speaker: Professor P. S. Biegler, of the State College of Washington. Attendance 10.

January 27, 1922, Davenport Hotel. Subject: "The Human Voice and Its Electrical Transmission." Speaker: Mr. John Mills of the Western Electric Company, New York.

Syracuse.—January 27, 1922, Chamber of Commerce. Brief discussions by local members on subjects pertaining to shop practise, etc. The sole effort in this meeting was to make it entirely practical for the benefit of those who are unable to follow the theoretical discussions usually presented at our meetings. Attendance 31.

Toronto.—January 13, 1922, Electrical Building, Toronto University. Subject: "Writing Engineering Reports and Specifications." Speaker: Mr. F. R. Ewart. Attendance 90.

January 27, 1922, Electrical Building, Toronto University. Subject: "Railway Signaling." Speaker: Mr. C. W. Parker, of the Canadian Pacific Railway. Attendance 93.

Urbana.—January 20, 1922. Business meeting. Attendance 7.

Utah.—January 20, 1922, Newhouse Hotel. First general meeting of the Engineering Council of Utah, of which the Utah Section of the A. I. E. E. is a member. Subject: "The Human Voice and its Electrical Transmission." Speaker: Mr. John Mills, of the Western Electric Company, New York. Light refreshments and a social hour followed the lecture. Attendance 335.

January 27, 1922. Gold Room, Commercial Club. Subject: "The Romance of Engineering." Speaker: Mr. Lafayette Hanchett. Refreshments were served. Attendance 120.

Vancouver.—January 23, 1922, Auditorium, Board of Trade. Subject: "Automatic Telephone Isolated Plants, as used in Industrial Plants." Speaker: Mr. F. H. MacGougan, of the Northern Electric Company. Attendance 13.

BRANCH MEETINGS

Alabama Polytechnic Institute.—February 7, 1922. Subject: "Electrically Driven Ships." Speaker: Professor Hill. Attendance 20.

University of Arkansas.—January 31, 1922. Election of officers as follows: Chairman, J. W. Booker; Vice-Chairman, J. A. Thompson; Secretary, B. R. Askew (reelected); Treasurer, L. G. Huggins. Attendance 15.

Brooklyn Polytechnic Institute.—January 5, 1922. Subjects: "Illumination in the Home," by Mr. F. M. Reast; and "The Atom," by Mr. Mills, of the Western Electric Company. Refreshments were served. Attendance 85.

University of California.—January 25, 1922. Subject: "Communication Service of the Bell Telephone Company." Speaker: Mr. D. I. Cone, of the Pacific Telephone & Telegraph Company. Attendance 27.

Case School of Applied Science.—February 9, 1922. Subject: "Electric Arc Welding." Speaker: Mr. J. C. Lincoln. of the Lincoln Electric Company, Cleveland, O. Attendance 52,

University of Cincinnati.—January 9, 1922. Subject: "Philosophy Applied to Engineering." Speaker: Professor G. A. Tawney. Attendance 62.

January 16, 1922. Subject: "Electrical Precipitation." Speaker: Mr. T. R. Watts, E. E. '22. Attendance 45.

January 30, 1922. Subject: "Esterline Meters, Their Design, Construction and Uses." Speaker: Mr. J. R. Petres, E. E. '22. Attendance 51.

Clarkson College.—January 10, 1922. General Electric Company films as follows: "King of the Rails," and lantern slide lecture on "Paper Mill Drive." Attendance 20.

Clemson College.—December 20, 1921. Subject: "The Heat Flow in Electrical Machinery." Speakers: Messrs.

Epting, Simmons and Rittenberg. Current Events by J. L. Weeks. Attendance 24.

January 17, 1922. Subject: "Automobile Ignition-Magneto vs. Battery." Speakers: Messrs. Hoog, Jones and Rice. Current Events by J. H. Erskine. Attendance 20.

Colorado Agricultural College.—January 16, 1922. The following moving pictures were shown: "Big Deeds," and "Queen of the Waves." Attendance 20.

University of Colorado.—January 12, 1922. Messrs. Cassell and Owen, electrical engineering students, gave an interesting demonstration of the wireless equipment of the Electrical Engineering Department. News items, market and weather reports, and several musical selections broad-casted by Dr. Reynolds, of the Reynolds Radio Company, Denver, were received with sufficient intensity and clearness to be heard by those present. At the conclusion of the broadcast, Dr. Reynolds called the University Station and a two-way telephone conversation was carried on. The voice from the twenty watt phone set of the University was reported by Dr. Reynolds as being very loud and the modulation good. Refreshments were served. Attendance 61.

Cooper Union.—January 14, 1922. Inaugural address by Mr. Towle, Instructor, followed by addresses by Messrs. Arthur Colledge, President of the Branch, and William A. Del Mar, Vice-President of the A. I. E. E. Metropolitan District. Mr. Herbert E. Shreeve, of the Western Electric Company, spoke on "Recent Advances of Telephone Transmission." Attendance 200.

Drexel Institute.—January 13, 1922. Subject: "Recent Developments in Power Plants," (illustrated). Speaker: Mr. Robert Hentz, of the Philadelphia Electric Company. Attendance 12.

Iowa State College.—February 2, 1922. Subject: "Automatic Telephony." Speaker: Professor E. R. McKee, of the Electrical Engineering Department. A two-reel film "The Dial of Destiny," furnished through the courtesy of the Automatic Electric Company of Chicago, was shown. Attendance 130.

Kansas State College.—January 9, 1922. Subjects: "Modern Illumination," by G. L. Garloch '22; and "Some Needs of Safety Protection for the Repairmen in Power Plants," by H. I. Tarpley '22. Attendance 56.

Kansas University.—January 12, 1922. Subjects: "Indirect Lighting," by Harry Hanlon; "The Niagara Falls Power Plant," by George Cochran; Thesis Reports by The Seniors. Attendance 39.

University of Kentucky.—January 16, 1922. Subject: "The Engineering Aspect of the Newspaper." Speaker: Mr. Harry Roberts, Advertising Manager of the Lexington Leader. Attendance 34.

Lafayette College.—January 9, 1922. Subject: "Transmission Lines and Power Distribution of Easton and Vicinity." Speaker: Mr. W. W. Perry, of the Pennsylvania Edison Company, Easton, Pa. Attendance 18.

January 13, 1922. Subject: "Electric Ship Propulsion," (illustrated). Speaker: Mr. Maxwell W. Day, of the General Electric Company, Schenectady, N. Y. Attendance 28.

January 16, 1922. Inspection trip to the Dock Street Station of the Pennsylvania Edison Company, Easton, Pa., under the guidance of Mr. W. W. Perry.

University of Maine.—January 11, 1922. Owing to weather conditions the announced speaker was unable to be present. Mr. Clinton R. Boothky gave an account of his summer's work with the Westinghouse Elec. & Mfg. Company. Attendance 30.

Massachusetts Institute of Technology.—December 15, 1921. This meeting was held under the auspices of the Boston Branch and the Combined Professional Societies of M. I. T. Subject: "Transmission Lines and Their Phenomena." Speaker: Dr. C. P. Steinmetz. Attendance 1100.

January 5, 1922. Meeting held under the auspices of the Electrical and Mechanical Engineering Professional Societies. Subject: "The Colfax Power Plant of the Duquesne Power and Lighting Company." Speakers: Messrs. Clarke and Galusha, of Dwight P. Robinson Company. Attendance 175.

January 26, 1922. Subject: "Recent Advances in Long Distance Telephony." Speaker: Mr. H. E. Shreeve, of the Western Electric Company. Attendance 65.

University of Michigan.—January 25, 1922. Joint meeting with Detroit-Ann Arbor Section of A. I. E. E. Subject: "The Relation of the Electrical Engineer to Fire Prevention and Fire Protection." Speaker: Mr. R. C. Loughead, of the Michigan Inspection Bureau of Fire Underwriters. The address was illustrated with motion pictures and slides. Attendance 110.

University of Minnesota.—February 1, 1922. Banquet and get-acquainted meeting, at Oak Grove Hotel. Attendance 107.

University of North Carolina.—January 19, 1922. Subjects: "Armature Winding," by O. L. Giersch; "Electric Fixation of Nitrogen" by O. R. Rowe; "The Muscle Shoals Development," by R. G. Koontz. Attendance 33.

February 9, 1922. Subjects: "Relays in Telephone Work," by W. M. Moore; "The Tesla Coil," by F. M. Spaugh. Attendance 28.

University of North Dakota.—January 10, 1922. Business meeting. Attendance 14.

University of Notre Dame.—February 6, 1922. Subjects: "Modern Train Lighting Systems," by W. Rauber; "Storage Batteries," by V. Brown. Attendance 21.

Ohio Northern University.—January 19, 1922. Mr. Witzler gave a detailed explanation of the wireless telephone, including the vacuum bulb possibilities in the future, after which he proceeded to tune his own set which he had hooked up for the occasion, and those present had the pleasure of listening to a concert given by the Westinghouse people at Pittsburgh. Attendance 50.

February 2, 1922. Subject: "The Development of the Steam and Water Turbine." Speaker: Mr. E. A. Erdman. Attendance 43.

Oklahoma A. & M. College.—January 31, 1922. Election of officers as follows: Chairman, Charles S. Folk; Vice-Chairman Ludwik Jehicka; Secretary-Treasurer, Ivan T. Knight. Attendance 18.

University of Pennsylvania.—January 12, 1922. Subject: "The Young Engineer in Big Corporations." Speaker: Mr. C. A. Hutchins, of the U. G. I. Company. Dr. Harold Pender gave a short talk on "Criticism." Attendance 29.

University of Pittsburgh.—January 11, 1922. Subjects: "The Use of Electric Apparatus in Its Relation to the By-Products Ovens," by D. H. Lauder; "The Personnel and Duties of the Signal Corps," by H. K. Doyle. Attendance 41.

January 18, 1922. Subjects: "Grounds," by Mr. A. H. Zinsser; "Development of the Telephone Transmitter," by Mr. E. G. Campbell. Attendance 35.

January 28, 1922. Subject: "Coal Mining." Speaker: Mr. R. B. Anthony. Attendance 38.

February 1, 1922. Talks as follows: Mr. W. W. Miller, on the Liberty Tunnels; Mr. C. L. Hughes, on the instrument testing department of the Duquesne Light & Heat Company; Mr. J. N. Lehman, on the method used by the Pennsylvania Railroad in repairing the engines. Attendance 40.

February 8, 1922. Subjects: "Hydroelectric Development of the West," by Mr. Blassingham; "Boiler Testing at the Springdale Power Plant," by Mr. Crandall. Attendance 39.

Stanford University.—January 26, 1922. An initiation and banquet was held at the Theta Xi House, thirteen new members being initiated. Refreshments were served, and speeches made by Chairman Becker and various members. Attendance 35.

Syracuse University.—December 15, 1921. Subject: "The Problems of Selecting a Suitable Frequency." Speaker: Mr. C. E. Van Orden. Attendance 9.

A. & M. College of Texas.—January 13, 1922. Subjects: "Comparison of Operation Costs of Rail Car, Trolley Bus and Gas Bus," by Mr. Silvus; "The Lightning Generator," (reference *General Electric Review*) by Mr. W. T. Stamps; illustrated lecture on "Waterside Station No. 2 of New York," by Mr. Q. B. Schaefer; outline of the work of Standardization of Rules as carried on by the A. I. E. E., by Mr. J. B. Straw. Attendance 40.

Virginia Polytechnic Institute.—January 30, 1922. Subject: "Wireless Telephony." Speaker: Mr. H. P. Gilbert. Attendance 41.

University of Virginia.—January 26, 1922. Subject: "Radio Central." Speaker: Mr. T. R. Bunting. Attendance 15.

State College of Washington.—January 24, 1922. Subjects: "The Vacuum Tube and its Application," and "The Human Voice and Its Electrical Transmission." Speaker: Mr. John Mills, of the Western Electric Company, New York. Attendance 160.

University of Washington.—January 10, 1922. Subject: "The Opportunities Awaiting the Engineering Graduate." Speaker: Mr. F. K. Kirsten. Attendance 45.

January 31, 1922. Meeting held in conjunction with Sigma XI. Subject: "Thermionic Valve and Its Application." Speaker: Mr. John Mills, of the Western Electric Company, New York. Attendance 250.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—Waldo C. Cole, 410 Mills Bldg., El Paso, Texas.
2.—E. W. Erikson, 214 University Club Bldg., St. Louis, Mo.
3.—E. L. Neil, Box 401, Palo Alto, Calif.
4.—R. W. Seem, 633 W. 74th St., Los Angeles, Calif.
5.—F. W. Smith, 500 Todd St., Wilkinsburg, Pa.
6.—Louis H. Wessels, 105 Union St., Jersey City, N. J.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL ***should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the Societies constituting the Federated American Engineering Societies, and* ***not*** *to the A. I. E. E.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case ***and forwarded to EMPLOYMENT SERVICE, as above.***

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

POSITIONS OPEN

TRANSMISSION LINE SUPERINTENDENT. Applicant must be conversant with practise in transmission lines, 100,000-volt, three-phase, 50-cycle. Must be capable of taking entire charge of transmission system of approximately 400 miles of line, must be familiar with both construction and operating work, and must be capable of handling native help. Reply stating age, experience, training and salary desired. Location India. X-1292.

EXPERT DIE CASTING ENGINEER for production work. Must have good personalty and good executive experience. Only men with die casting experience will be considered. V-13.

ELECTRICAL ENGINEERING GRADUATE for position as sales engineer with large electrical manufacturing concern in Middle West. Splendid opportunity for right man. State age and qualifications in detail in first letter. X-1520.

ELECTRICAL ENGINEER for remote control and substation design. Must be thoroughly familiar with use of relays. Must be electrical engineering graduate, under 45 years of age. Full details of education, experience, salary and time available should be given in first letter. Location, Pa. V-43.

ASSISTANT TO CHIEF ENGINEER of large electric light and power company located in the Middle West. Must be technical graduate with at least five years experience in engineering or distribution department of modern utility. Must have good sound business judgment, some knowledge of construction accounting, estimating and constructing overhead and underground distribution, etc. Excellent opportunity for young man with ambition. V-72.

GRADUATE ENGINEER or its equivalent in electrical engineering. Degree not required but knowledge must be well founded. Age 25-35 years. Work almost entirely with motors of different sizes and types. Design and layout of details, etc. Testing and service work. Position may lead into a number of new fields. Experience on, and knowledge of, electrical motors, their design and operation absolutely essential. Good personality with ability to meet people. Initiative and tact. Will largely have to do with application sent to customer's office and factory and will have to meet engineers and executives. May have to do sales work and will be under direction of both sales and engineering departments. Sales experience not absolutely necessary but possibilities must be there. Must be able to express ideas on drawing board, but will not be tied there. Location, Ohio. V-75.

ELECTRICAL ENGINEER for general work in testing laboratory. Location, New York City. V-87.

CHIEF ELECTRICIAN for cement plant, technical graduate, with some practical experience as chief electrician with some manufacturing plant. Location, Kansas. V-89.

ENGINEER to take complete charge of modern power plant consisting of a G. E. Curtis type turbine and alternator driven by Skinner engine. Air compressors used in the plant in connection with cutting of coal. Plant operates condensing using Ingersoll Rand condenser. Boilers fired by stokers, using Files Engineering Company's mechanical feed stokers. Location, Kentucky. V-124.

ENGINEER on publicity and relating matters wanted by manufacturer of electrical apparatus. Graduate electrical engineer with experience in manufacturing, engineering or selling rather than strictly publicity work. An opportunity for an electrical engineer who has found his work uncongenial to try himself in the publicity field. V-135.

ELECTRICAL ENGINEER with technical education capable of taking complete charge of electrical equipment in plant having installed approximately 10,000-horse power d-c. and a-c. motors and generator service. Should have had practical experience in operation of large industrial plant using modern electric equipment. State salary expected. Location, Boston, Mass. V-136.

ENGINEERS experienced along the line of electric welding equipment, etc. Location, New Jersey. V-148.

FIELD ENGINEER capable of taking full charge of construction and modern power houses, installation of electrical and mechanical equipment. Write giving experience, age, salary expected and at least three references. Location, Pa. V-156.

INDUSTRIAL ENGINEER thoroughly familiar with wood working machinery and plants. Must be able to improve process of manufacture and conservation of materials. Should have experience in the manufacture of veneers from the log to the finished product and other similar wood by-products. Location, New York, Vermont, & Wisconsin. V-157.

POWER PLANT ENGINEER. Must be able to analyze power plant costs especially in industries. Also investigate results obtained with different types of equipment such as uniflow engines, Diesel, etc. Location, Pittsburgh, Pa. V-161.

SOLICITOR for patent department. Graduate electrical engineer 1920-21 with slight experience if possible or acquainted with telephone work. Will be entirely office work. V-163.

WORKS ENGINEER AND MASTER MECHANIC to be in general charge of power house, heating, lighting, repairs and maintenance of building and machinery and possibly, tool design. Location Michigan. Application by letter giving age, education and experience. V-181.

GENERAL SUPERINTENDENT for food products factory making jams, jellies and preserves. Must have knowledge of the manufacture, packing, shipping, etc., of food products. Location, New York City. V-182.

SALES ENGINEER between 25 and 30 years having had several years sales experience thoroughly familiar with electrical engineering from standpoint of motor application. Application by letter. V-184.

TECHNICAL MAN bright, energetic for commercial department, to solicit engineering work. Must be technical graduate and knowledge of ice making and refrigerating work; must be American citizen. Application by letter only. Location, New York City. V-185.

MASTER MECHANIC to take charge of the entire maintenance work in a gas plant. Must be able to direct in detail the repairs of electric motors and control apparatus, including rewinding armatures and stators. State salary desired and give detailed professional record. V-186.

ENGINEERS experienced in the sale and distribution of alternating-current induction motors and the specialties which go with such motors. Write giving complete description of age, education, previous connection, previous business experience, etc. Location, Conn. V-205.

RECENT GRADUATE from either M. I. T., Stevens or Cornell to enter course of training with mercantile house on motor truck operation and general office cost work. Application by letter. Location, New Jersey, Massachusetts, Pittsburgh. V-216.

RESEARCH ENGINEER, combustion of low quality or value fuels. V-246.

ELECTRICAL ESTIMATOR. Must be good draftsman and experienced in electrical contracting. Age under 30 years. Location, New York City. V-259.

ILLUMINATING ENGINEERS (2 or 3). Need not be technical graduate. Must know principles of illumination, be able to go into factory offices, or stores, test engines, etc., and propose and carry through proper illumination installations. A No. 1 man. Application by letter. Location, New Jersey. V-273.

INSTRUCTOR in electric house wiring, (part time) evening position. Class will meet every Monday, Wenesday, and Friday from 7:30 to 10:00 p. m. Location, N. Y. City. V-275.

MECHANICAL AND ELECTRICAL ENGINEER. Problem will be along following lines. Determine electrical power factor monthly. Determine water evaporation per pound of coal. Calculate line losses for steam and electrical power. Be familiar with recording watt and ammeters and their calculations. Have knowledge of both water and hydraulic work. Indicate and read steam engine charts. Be familiar with belt power transmission. Location, New Jersey. V-287.

INSTRUCTOR in electrical engineering who has had experience in radio communication, who has enthusiasm and initiative in the direction of radio development. Must be college graduate in electrical engineering with training and ability to handle theory as well as practise radio work. Must have good character, tact, judgment and ability to get along well with colleagues. Should also have good "telephone voice" as we hope to do considerable work in radio-telephony. Duties will be entirely confined to radio work and he will be expected to act as station operator in whatever work is developed. Will be employed on 12-month basis, with one month for vacation. Application by letter giving age, education and experience. Location, Middle West. V-294.

SALES ENGINEER having had considerable experience selling electrical equipment and well versed in electrical theory to sell electric motor trucks. Application by letter. Location, New York City. V-298.

ENGINEER to take charge of management department of a real estate office. Must have had actual experience in renting and operating high class office building. Location, New York City. V-303.

ELECTRICAL ENGINEER capable of designing and perfecting electrical railway signal apparatus. Location, New York State. Application by letter. V-305.

ENGINEER familiar with overhead line construction power and telephone. Location, Wash. D. C. V-328.

ENGINEER. Experienced, capable of designing and developing motor driven household appliances. Must be experienced and capable of independent work. State fully, experience, present occupation, age, and salary expected. V-359.

SMALL MOTOR ENGINEER. Technical graduate having several years experience in design and development of fractional horse power and small capacity motors. Excellent opportunity. State fully, experience present occupation, age and salary expected. V-360.

EXECUTIVE SALSEMAN to assume marketing problems of growing middle western concern manufacturing a commodity nationally used in large quantities by makers of motors, transformers, coils, etc. We sell through manufacturers' agents in developed territories. Other areas must be developed to attract agents. All this calls for a fielding sales manager as he will work single handed until his own results justify adding salesmen. We are looking for a proved success but will consider a high pressure salesman accustomed to this class of trade and who is coming fast. In either case appointee must control enough business to make him a success from the start. For such a man we will make an opportunity. V-380.

MEN AVAILABLE

ELECTRICAL AND MECHANICAL ENGINEER, technical graduate, age 34, unmarried. General Electric test. Seven years experience in design and development of electrical power machinery and steam turbines. Lubricating engineering experience. Lieutenant U. S. Navy during war. Member A. I. E. E. Desires opportunity for advancement with manufacturer or power concern. Would consider sales work also. E-3198.

INDUSTRIAL HEATING ENGINEER. Assoc. A. I. E. E. Age 29, technical graduate, 1914. Desires position with central station company or manufacturer in sales engineering work on electric heating in industrial processes. Thoroughly familiar with heating field in all temperature ranges and experienced in electrical sales, purchasing, construction, operating and preferred stock work. E-3199.

ELECTRICAL ENGINEER. Technical education, Assoc. A. I. E. E. Former engineering officer U. S. Navy. Wide experience with manufacture, installation and maintenance of d-c. equipment and storage batteries. Also experience with automotive electrical work, railway car lighting, and factory maintenance with a-c. equipment. Age 33. Married. Located in Kansas. E-3200.

ELECTRICAL ENGINEER, age 36; single. Ten years experience in power station design, construction, operation and industrial engineering. Assoc. A. I. E. E. Extensive executive and purchasing experience. Desirous of entering engineering sales field or executive position. Salary $3500-$5000. Available at once. E-3201.

TECHNICAL STUDENT, age 23, graduating from five-year course in electrical engineering at Cooper Union Night School this April, desires position with electrical engineering concern offering advancement and a future. Location vicinity of N. Y. at present, but willing to go anywhere after April. Salary a secondary factor. Seven years varied experience. E-3202.

ELECTRICAL ENGINEER. Married, B. Sc. degree, electrical and mechanical shop courses, six months sales, one year automatic telephone operation, four years switchboard and automatic control apparatus design, (section leader) and two years power and telephone installation foreman. Desires permanent position in Canada or Eastern States. E-3203.

ELECTRICAL ENGINEER. Assoc. A. I. E. E. Technical school education. Six years practical work with leading manufacturers. (Westinghouse Electric 2½ years) on all forms of apparatus, *good knowledge* of small motor production desires change from present position. A-1 references. Married, age 27. Would like foremanship or similar work. Minimum salary $40 per week. E-3204.

ENGINEER. Assoc. A. I. E. E. Available at once. University man, married, age 33, with 11 years engineering, executive, and sales experience, including 19 months G. E. test course and 14 months as inspector of British Army plants in France and Flanders. Prefers to take agency for manufacturers in Canada or office executive or sales position. E-3205.

EXECUTIVE ASSISTANT to HOLDING COMPANY OFFICIAL. Ten years intimate contact with utility management, operating problems and practises obtained by interviewing executives and engineers in various parts of the U. S. Special attention directed to means of establishing better public relations, securing most reliable and economical operation, and building load. Technical graduate, has gone through "over-alls" stages of operation, member of A. I. E. E. and I. E. S. and technical committees, participated in every Nela convention for last ten years. Can detect conditions that need correction and determine remedy. Engaged at present but desirous of applying knowledge in different manner. E-3206.

MECHANICAL and POWER ENGINEER, technical graduate B. S. and M. E., age 30, eight years broad experience, machine shop, metallurgy, sugar engineering, industrial and power plant practise, operation, design, layout, calculations, heating, distribution of steam, water, etc., investigation, reports. Executive and business ability. E-3207.

ELECTRICAL ENGINEER. Assoc. A. I. E. E. Age 27, single, technical graduate 1919. One year factory experience on small electrical motors, one year sales of power apparatus and service work. Employed at present but available on reasonable notice. Locate anywhere. E-3208.

ELECTRICAL ENGINEER, age 24, college graduate, married, eighteen months General Electric Company test, desires position with public utility company or with consulting engineer, having good opportunities for advancement. Location in West preferred. Assoc. A. I. E. E. Available at once. E-3209.

ELECTRICAL ENGINEER, qualified as superintendent of power, electrical supt. or maintenance engineer, available now. College graduate, fifteen years experience. Salary $3600. Would consider opportunity to try myself on commercial work where operating and construction experience might be considered valuable qualification. E-3210.

ELECTRICAL ENGINEER. Assoc. A. I. E. E., technical graduate 1915, 2 years Westinghouse test, 2 years U. S. Navy, 1 year construction work, 2 years Service Engineer. Desires position with large construction company or with the engineering or operating department of power company. Would consider position as electrical engineer for large industrial or mining company. Available on short notice. E-3211.

ELECTRICAL ENGINEER technical graduate in electrical engineering 1907. Age 38. Married, ten years in charge of construction and maintenance of powerhouse and substation equipment for central station company. Desires position in electrical engineering. Available on short notice. E-3212.

ENGINEER, single, age 27, technical training, 11 years electrical experience with construction companies, chiefly substations and power houses of high and low-tension voltages, supervising and under supervision, willing to render any kind of services at any place required; familiar with safety control wiring. Assoc. A. I. E. E. E-3213.

ELECTRICAL ENGINEER, M. I. T. Graduate, Member A. I. E. E. Fourteen years in charge of design, sales, construction, inspection of industrial and public utility steam-electric plants in Chile, Santo Domingo, New York and Boston. Speaks Spanish. Desires position either as New York representative for power station equipment or as electrical engineer. Salary $4000. E-3214.

ELECTRICAL ENGINEER, age 32, married. Technical graduate in electrical engineering. 11 years experience in power plant construction, equipment installation and industrial plant operation, good executive. E-3215.

PRODUCTION OR SALES ENGINEER, 1917 graduate, age 28, married. Experience in planning, routing, scheduling, despatching and stores. Also engineering sales and correspondence work. Desire employment that will offer a future based upon the results which I am able to show. E-3216.

ELECTRICAL ENGINEER, Member A. I. E. E. Age 32. Eleven years experience in manufacture, designing and sales of electric fans and small motors for various other purposes. About one year executive experience. Employed by large electrical manufacturing concern but desires a change. E-3217.

INSTRUCTOR IN ELECTRICAL ENGINEERING, eastern engineering college of highest grade, desires part-time work in connection with correspondence school courses. Has had practical experience electrical construction and installation. E-3218.

GRADUATE ELECTRICAL ENGINEER, age 31, married, protestant. Past three years engineering department well-known consulting firm, design power-houses, etc. Engineering officer U. S. Navy during war. Previous experience—Westinghouse test floor, engineering and operating departments large operating company. Good organizing and executive ability, excellent credentials. Detail information gladly furnished. E-3219.

TECHNICAL GRADUATE, age 29, Assoc. A. I. E. E., 2 years G. E. test, 4 years responsible experience in steam power plants. Now general superintendent, 3000-kw. modern turbine station, small electric railway and 240-ton ice plants. Desires position with consulting engineer which offers chance for advancement. Present salary $3400. E-3220.

WANTED. Position with power or central station company in charge of distribution and contracting business in small town. Fifteen years experience high-tension and textile engineering, estimating and supervision. Age 35. Graduate E. E. Assoc. A. I. E. E. and I. E. S. E-3221.

SOMEWHERE an industrial plant is being planned which will require an engineer to lay out, install and maintain electrical equipment. My technical training and thirteen years broad experience as mechanic and supervisor enable me to say with confidence that I can handle this class of work.E-3222.

ELECTRICAL ENGINEER with 17 years practical experience in industrial plant, repair shop, testing trouble and installation work out on the road. Can furnish best of references, prefer New Jersey or New York. Age 34 married, available 30 days, salary $2600 minimum. E-3223.

ELECTRICAL-MECHANICAL ENGINEER, B. S. E. E. degree; Assoc. A. I. E. E., married, age 35. Nine years varied experience; three years construction and two years operation in hydro- and steam-electric power stations on Pacific Coast. Over two years in executive capacity. Two years as sales engineer on power plant machinery, one year on design and at present teaching electrical engineering at State University. Desires position of taking charge of electrical department of large industrial plant or as assistant to consulting engineer. Location Pacific slope or Northwest. Salary $3000. E-3224.

ELECTRICAL ENGINEER, Member A. I. E. E. 20 years experience. Design, construction operation. Large hydraulic power plants, industrial plants, 110,000-volt and low-tension transmission lines. Electric furnace and electrolytic plants. Can fill chief engineer position or consulting work. E-3225.

ELECTRICAL ENGINEER, 33, married with technical training, manufacturing and industrial experience desires to connect with growing Canadian company where initiative, analytical ability and perseverance coupled with sound knowledge of fundamentals and good practical experience can be used to advantage. Present salary $3300. E-3226.

COMMERCIAL EXECUTIVE, PURCHASING MANAGER OR SALES ENGINEER. The president of his present connection says: "Risk is eliminated in an investment in this man's services—he has the habit of success." Now vice-president and general manager of going concern; Cornell graduate; Member A. I. E. E. and A. S. M. E. E-3227.

TECHNICAL Graduate, University of Michigan. class of 1919, desires to locate with electrical manufacturing company in development or research department. Experience has been in development department of large Eastern manufacturing company, on switchboard apparatus. Willing to undertake any position in electrical company along the line of electrical engineering, except selling. Married, no children, age 24, and do not care for sales work on account of wanting to locate permanently. Location desired—Michigan, Ohio or Indiana. E-3228.

MECHANICAL AND ELECTRICAL ENGINEER, 30 years experience electric railway and utility power engineering, steam plants, steam railroads electrification, rolling stock, trolley construction, power transmission, electrolysis, rehabilitation, valuation; nearing completion four-year engagement rehabilitating large combination utility, desires connection by June with steam railroad, electric utility or manufacturing company power department. E-3229.

ELECTRICAL ENGINEER, age 26, technical education, 7 years experience contracting, testing and construction. Last three years with electrical traction company in executive capacity in connection with substation construction. Would prefer entering sales organization of electrical manufacturing concern. E-3230.

GRADUATE ELECTRICAL ENGINEER. Twelve years experience designing, constructing, operating and appraising electrical properties, industrial plants, public utilities, railway terminals etc. Position desired with progressive firm in North Central States. Available on short notice. E-3231.

GRADUATE ELECTRICAL ENGINEER. Age 27. Married, at present employed, would like to get into power plant work. Will consider location in small city, but would like Middle West. Services available on short notice. E-3232.

ENGINEERING INSTRUCTOR. University graduate, Associate A. I. E. E., age 30, married, desires position as instructor in engineering or scientific courses. Nine years practical electrical and mechanical experience. Teaching mathematics at present. Good references. Available on reasonable notice. E-3233.

ELECTRICAL ENGINEER. Desires position in nature of superintendent or assistant superintendent of steam electric power plant. Experienced in over head construction, estimating costs, electrical distribution, meter engineering, power plant efficiency and combustion. Two years experience supervision. Age 34 years. E-3234.

GRADUATE ELECTRICAL ENGINEER. Desires connection with firm of consulting engineers. 2½ years G. E. Co. test and field experience now employed with public service company. Age 25. Single. Location anywhere. E-3235.

ELECTRICAL ENGINEER. Age 24, married, 2½ years G. E. test, 8 months foreman of a G. E. Test Department. Experience in factory efficiency engineering, layout and maintenance, also steam and hydraulic operation. Now employed as assistant electrical superintendent of power plant and paper mill. Present salary $50 per week. Available two weeks' notice. E-3236.

GRADUATE ELECTRICAL ENGINEER. Age 27, married, desires position with light and power or traction company. One year junior engineer with power and traction company, all departments, two years general business experience. E-3237.

GRADUATE ELECTRICAL ENGINEER. Age 25. Desires position where advancement can be made. Have been an instructor in college. Have also had experience in electrical construction and telephone engineering. E-3238.

ELECTRICAL ENGINEER, technical graduate; Assoc. A. I. E. E. Age 28. Six years experience in testing laboratory radio, chief engineer of marine installation and maintenance; remote control, machine tool application, estimating and construction work. Desires permanent position with well established company, planning, estimating and following up progress of jobs. Location preferred Newark or New York City; available one month. E-3239.

TECHNICAL GRADUATE IN ELECTRICAL ENGINEERING looking for position to gain some good practical experience. Very little practical experience but willing to learn. Available June 1922. Construction work or chance on some power development desirable. E-3240.

TECHNICALLY TRAINED MAN, 24 years old with extensive experience in the engineering of electrical construction work, wishes to join the sales force of concern dealing with contractors and engineers. E-3241.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED FEBRUARY 16, 1922

AGARWALA, MUNNALAL C., In Charge of Electric Works, Empire Engineering Company, Cawnpore, India.

*AGUADO, JOSE, Student, Johns Hopkins University, Baltimore, Md.

ALLEN, JOSEPH WILLIAM, Aero Mechanical Engineer, Engineering Division, Air Service, McCook Field; res., 116 Shaw Ave., Dayton, Ohio.

AMERMAN, ALBERT LOTT, Engineer, Sperry Gyroscope Company, Manhattan Bridge Plaza, Brooklyn; res., 32 Lenox Road, Rockville Centre, N. Y.

*AMSDEN, BURTON ROBERT, Power Engineer, The New York Edison Company, Irving Place & 15th St., New York, N. Y.

ANDERSON, EDWARD BRUCE, Sales Engineer, F. R. Jennings Company, 805 Ford Bldg., Detroit, Mich.

ANDERSON, SIDNEY EDWIN, Telephone Engineer, Western Electric Co., 463 West St., New York, N. Y.

ARCHER, JOHN WILLIAM, Senior Equipt. Man, American Tel. & Tel. Company, 416 7th Ave., Pittsburgh, Pa.

ATKINS, CHARLES ELWOOD, Assistant Distribution Engineer, Union Electric Light & Power Co., Lockwood & McClure Aves., Webster Groves, Mo.

BAER, WALTER O., Electrical Engineer, Cutler-Hammer Mfg. Company, Milwaukee, Wis.

*BAILEY, GEORGE ALDRICH, Testing Dept., Western Electric Company, 210 W. 34th St.; res., 133 E. 84th St., New York, N. Y.

BALL, FRANCIS L., Manager, Fitchburg Gas & Electric Company, 537 Main St., Fitchburg, Mass.

*BALLENGER, ALBERT RHETT, with J. S. Ballenger, Wellford, S. C.

BARAT, SHIVAKRISHNA, Electrical Engineer, Messrs. F. & C. Osler, Ltd., Kashmir Gate, Delhi, India.

*BAUER, LOUIS HENRY, Assistant Engineer, Louisville Railway Company; res., 1309 Morton Ave., Louisville, Ky.

BAULCH, BERT LEO, Assistant District Sales Manager, Northern Electric Company, Ltd., 131 Simcoe St., Toronto, Ont.

BAXTER, CHARLES EMIL, Telegraph & Telephone Engineer, Michigan Central Railroad, Detroit, Mich.

*BEARDMORE, ALBERT EDWIN, 515 Johnson Ave., Warren, Minn.

*BELL, FRANKLYN EVELYN, Stone & Webster, Inc., Hartford, Conn.

BENNETT, JOHN SAMUEL, Superintendent of Operations, University of North Carolina, Chapel Hill, N. C.

*BENNETT, RALPH S., Sales Engineer, General Electric Company; res., 182 Brown St., Pittsfield, Mass.

BION, JOHN WILLIAM, Chief Electrician, R. Hoe & Company, 504 Grand St., New York; res., 950 Jefferson Ave., Brooklyn, N. Y.

*BLUME, WILLIAM EDWARD, Engineer, Service Electric Company, 212 Center St., New York; res., 50 Bay 25th St., Brooklyn, N. Y.

*BOCKENEK, DAVID MAURICE, Electrical Tester, Westinghouse Electric & Mfg. Company, 398 Center St., Wilkinsburg, Pa.

*BOWMAN, JOHN DRUMMOND, Engineering Dept., Central Maine Power Company; res., 2 Elm Terrace, Waterville, Maine.

BRANNIGAN, EDWARD J., Engineer, Scovill Manufacturing Company, Waterbury; res., 176 Cherry St., Naugatuck, Conn.

*BRENNAN, HAROLD B., Designer, Switchboard Dept., General Electric Company, Schenectady; res., 26 Walnut St., Cohoes, N. Y.

BRENTON, WALTER, Assistant to Superintendent of Portland Stations, Northwestern Electric Company; res., 682 E. 56th St. North, Portland, Ore.

*BRICKSON, ROLF ARNULF, Telluride, Colorado.

BRIDGES, FRANK ROWLAND, Electrical Assistant, Boston Elevated Railway Company; res., 12 Hawthorne St., Boston, Mass.

BROWN, JOHN H., Superintendent, Electrical Construction, Hotel Astor, New York; res., 1749 Richmond Terrace, West Brighton, S. I., N. Y.

*BUCHAN, CHESTER EDWARD, Superintendent of Meters, Apple River Milling Co., Inc., & Colfax Light & Power Co., Amery, Wis.

BURROWES, CLEMENT, Electrical Engineer, Waimairi County Council, North Road, Papanui, Christchurch, N. Z.

CARLSON, CARL O., Local Field Engineer, Public Service Electric Company, 75 River St.; res., 28 Astor St., Newark, N. J.

*CARPENTER, PHILIP MARTIN, Lighting Engineering Dept., Hartford Electric Light Company; res., 44 Ashley St., Hartford, Conn.

*CARRANZA, JESUS, Electrical Engineer & Contractor, "Aztec Electric Company," Mexico City, Mexico.

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*CASKEY, ARTHUR DAVID, Engineer, Distribution Dept., Public Service Company of Northern Illinois, 10 Illinois St., Chicago Heights, Ill.

CASTRO, CARLOS, Inspector, Western Electric Co., 401 Hudson St.; res., 163 W. 88th St., New York, N. Y.

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CLAPAROLS, MANUEL, Consulting Engineer, The College of Wooster, Wooster, Ohio.

CLARK, FRANK LYNDS, Martinez, California.

CLARKSON, BEN, Salesman, Apparatus & Supplies, Tel-Electric Company, Houston; res., 127 Henrietta St., San Antonia, Texas.

*COGAN, CHARLES MICHAEL, Switchboard Designing Engineer, General Electric Company; res., 24 Van Vranken Ave., Schenectady, N. Y.

COLLINS, HAROLD WILSON, Electrical Tester, The Detroit Edison Company; res., 1744 Seward Ave., Detroit, Mich.

CONLEE, CARLTON NEWCOMB, Inspector, Chicago Telephone Company, 212 W. Washington St.; res., 928 E. 62nd St., Chicago, Ill.

*CORY, GEORGE LEWIS, Student, Otis Elevator Company, 250 11th Ave.; res., Y. M. C. A., 318 W. 57th St., New York, N. Y.

COUGHLIN, JAMES E., Jr., Engineer, Commonwealth Edison Co., 72 W. Adams St.; res., 521 W. 56th Place, Chicago, Ill.

*COVINGTON, PAUL T., Golding Mfg. Company, 30 Church St., New York; res., 129 Columbia Heights, Brooklyn, N. Y.

COWDERY, C. A., Electrical Engineer, General Electric Company, Bridgeport Works; res., 1501 W. Broad St., Stratford, Conn.

CRAIGEN, EWART GLADSTONE, Construction Foreman, A. S. D. Engineering Dept., Canadian General Electric Co., Toronto, Ont.; res., 676 Thurlow St., Vancouver, B. C.

CRANAGE, HERBERT AUBREY, Assistant Foreman of Laboratory, Leeds & Northrup Company, 4901 Stenton Ave., Germantown, Philadelphia, Pa.

CROFT, JOHN PAUL, Telephone Central Office Man, Bell Telephone Company of Pa.; res., 308 W. James St., Lancaster, Pa.

CROSSETT, MARTIAL CLAUDE, Assistant Chief Electrician, Commonwealth Steel Company; res., 2211a C St., Granite City, Ill.

*CUFFE, FREDERICK WILLIAM, Chief Engineer, Canadian Edison Appliance Co., Ltd.; res., 232 William St., Stratford, Ont., Canada.

*CULVER, LAURENCE ROSENCRANS, Student Assistant, Electrical Engineering Dept., Mass. Institute of Technology; res., 19 Willard St., Cambridge, Mass.

CUNNINGHAM, JAMES A., Wireman, Union Electric Light & Power Company; res., 2822a Blair Ave., St. Louis, Mo.

CURTIS, GEORGE GRAYDON, General Manager, Northern Wayne Electric Light & Power Company, 34 Main St., Wolcott, N. Y.

*CURTIS, THOMAS R., Electrical Engineer, Western Electric Company, Hawthorne; res., 904 Hayes Ave., Oak Park, Ill.

DAUCHY, CHARLES H., Electrician, Iowa Railway & Light Company, Cedar Rapids, Ia.

DAY, J. W., Superintendent of Construction, Ne Page McKenny Company; res., 3731 Meridian St., Seattle, Wash.

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*DOBBIE, PERCY ACTON, Assistant Engineer, New York Telephone Company, 104 Broad St., New York, N. Y.; res., 62 Arnold Terrace, S. Orange, N. J.

*DONOVAN, WILLIAM McKINLEY, Student Engineer, Westinghouse Elec. & Mfg. Company, E. Pittsburgh; res., 1010 Mill St., Wilkinsburg, Pa.

*DOUGLASS, WALTER JOSEPH, Engineer, Jay Insulating Compounds Company, 110 W. 40th St., New York; res., 148 Beach 113th St., Rockaway Park, N. Y.

*DOWNER, CHARLES BODDIE, Student Engineer, Testing Dept., General Electric Company; res., 1399 Eastern Parkway, Schenectady, N. Y.

*DUBSON, JOHN F., West Penn Power Company, Spring City, Pa.

DUCEY, WALTER JAMES, Engineering Draughtsman, Consumers Power Company; res., 429 W. Morrell St., Jackson, Mich.

DUFF, WILLIAM P., Engineer, General Electric Co., New Haven, Conn.

*DUGUID, RUSSELL HOWARD, Electrical Inspector, Pacific Electric Railway, 689 Pacific Electric Bldg., Los Angeles; res., 314 S. Chester, Pasadena, Calif.

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DUNN, CAVEN HALL, Testing of Electrical Apparatus, Canadian General Electric Co; res., 193 Dalhousie St., Peterboro, Ont., Canada.

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*ENGLAND, GLENN L., Electrical Draftsman, Western States Gas & Electric Company, Stockton, Calif.

*ENGQUIST, VICTOR EMANUEL, Valuation Engineer, St. Paul Gas Light Company; res., 931 Clark St., St. Paul, Minn.

*ERB, HENRY GUY, Industrial Division, Westinghouse Elec. & Mfg. Co., 165 Broadway, New York, N. Y.; res., Caldwell, N. J.

*ESTABROOK, HARRY EUGENE, Engineer, New York Telephone Company, 104 Broad St.; res., 227 N. High St., Mt. Vernon, N. Y.

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FULLER, WALLACE JOSEPH, Line Foreman, Bureau of Power & Light, City of Los Angeles, Public Service Bldg.; res., 211 S. Chicago St., Los Angeles, Calif.

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*GRANT, ALLAN QUARTON, Estimator, Western Electric Company, Inc., Hawthorne Station; res., 3708 Lexington St., Chicago, Ill.

GRAY, BURDETTE F., Travelling Meter Man, Canadian Westinghouse Company, Ltd., Hamilton, Ont., Canada.

*GRAYMAN, JACOB, Jr., Electrical Engineer, Transit Commission, 49 Lafayette St., New York; res., 25 Siegel St., Brooklyn, N. Y.

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GROSS, JAY C., Electrical Superintendent, Stackpole Carbon Company, St. Marys, Pa.

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HAINES, HAROLD G., Electrical Designer, Morgan & Wright, Jefferson Ave. & Bellevue, Detroit, Mich.

*HANNAH, PAUL DIXON, Student Engineer, Transmission & Protection Engineering Dept., Southwestern Bell Telephone Co.; res., 3942 Lindell Blvd., St. Louis, Mo.

*HARTMANN, FRANK JACOB, General Tester, New York Edison Company, 92 Vandam St., New York; res., 63 Greene Ave., Brooklyn, N. Y.

HAWLEY, IRVING GOODRICH, Load Dispatcher, Adirondack Power & Light Corp., 2518 Broadway; res., 705 16th St., Watervliet, N. Y.

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HOMAN, EDMUND LEWIS, Turbine Engineer, General Electric Company, W. Lynn; res., 14 State St., Marblehead, Mass.

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HORN, CHARLES, Electrician, Consolidated Shipbuilding Corp., Morris Heights; res., 325 E. 163rd St., New York, N. Y.

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HULL, ALEM PRICE, President, The Gas & Electric Shop, Inc., Montgomery, Penn.

*HYMAN, WILLIAM H., Electrical Instructor, Board of Education, Borden & Van Alst Aves., Long Island City; res., 127 7th St., New York, N. Y.

IRVINE, ROBERT P., Trouble Dept., Cleveland Electric Illuminating Company; res., 3501 Storer Ave., S. W., Cleveland, Ohio.

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KLINGE, RICHARD AUGUST, Builder, Owner & Constructor of Telephone Plants; res., 301 Columbia St., Pasco, Wash.

KLUGER, ALBERT, Jr., Electrical Engineer, Transit Commission, 49 Lafayette St.; res., 525 W. 175th St., New York, N. Y.

KLUGMANN, GUSTAV F., Jr., Electrician, American Bakery Company; res., 4911 S. Compton Ave., St. Louis, Mo.

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*KNUT, ALEXANDER, Electrician, Merchants Refrigerating Company, 17th St. & 10th Ave., New York; res., 2954 Amboy Road, Oakwood Heights, S. I., N. Y.

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*LOOMIS, ALVIN J., Construction Work, Western Electric Company; res., 5632 49th Ave., S. W., Seattle, Wash.

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*MACAROW, FRED G., Assistant Engineer, American Tel. & Tel. Co., 195 Broadway, New York; res., 17 Fort Greene Place, Brooklyn, N. Y.

MACDONALD, GEORGE A., Engineer, Distribution Dept., City of Los Angeles, Bureau of Power & Light, Public Service Bldg., Los Angeles, Calif.

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MacPADDEN, AUGUSTUS LEO, Cost Supervisor, Manufacturing General Dept., General Electric Company, Schenectady, N. Y.

MARK, FRANCIS PAUL, General Line Foreman, Depew & Lancaster Light, Power & Conduit Company; res., 9 Maple Ave., Lancaster, N. Y.

*MARTIN, WENDELL L., Engineer, Testing Laboratory, General Electric Company; res., 1445 Taylor St., Ft. Wayne, Ind.

MARTINET, EUGENE F., Experimental Engineer, P. A. Geier Company; res., 7616 Union Ave. S. E., Cleveland, Ohio.

MARUYAMA, SHIGERU, Manager of Rolling Stock & Repair Shop, Hanshin Electric Railway Company, Osaka, Japan; Mitsui & Company, 65 Broadway, New York, N. Y.

MASON, WILLIAMSON WILSON, Inspection Foreman, Western Electric Company, 1196 E. Grand St.; res., 852 Jersey Ave., Elizabeth, N. J.

MATHEWSON, DANA, Eastern Massachusetts, Street Railway Company; res., 190 Washington Ave., Chelsea 50, Mass.

MAULDIN, THOMAS RODOLPHUS, Hydro-Electric Station Operator, Georgia Railway & Power Co., Tallulah Lodge, Ga.

MAXWELL, JOHN FRANCIS, Electrical Checker & Designer, Stone & Webster, Inc., 147 Milk St., Boston, Mass.

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McLOAD, KENNETH, Sales Engineer, Westinghouse Electric & Mfg. Company, St, Louis, Mo.

MESSENT, KEITH S., Testing Dept., British Thomson-Houston Co., Ltd., Rugby, Eng.

MESSNER, ROY LEONARD, Transmission Maintenance Engineer, The Pacific Tel. & Tel. Company, 309 E. 8th St., Los Angeles, Calif.

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*MILLER, GEORGE WALLACE, Supervising Engineer, Commonwealth Electric Company; res., 1509 Laurel Ave., St. Paul, Minn.

MILLER, JOHN H., Master Mechanic, William Wharton Jr. & Company, Inc., Easton, Pa.

*MILLER, JAMES SHANNON, Jr., Assistant Professor of Experimental Engineering, University of Virginia, University, Va.

*MILLER, REXWELL DELBERT, Student Engineer, Pacific Tel. & Tel. Company, Sheldon Bldg., San Francisco; res., 2115 Hearst Ave., Berkeley, Calif.

MINTEER, EDWIN CAMPBELL, Salesman, Westinghouse Electric & Mfg. Co., 425 E. Water St., Milwaukee; Madison Club, Madison, Wis.

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MOON, J. LESLIE, Induction Motor Engineering Dept., General Electric Company; res., 2919 Shawnee Drive, Ft. Wayne, Ind.

*MOORE, CORMAN E., Engineering Assistant to Vice-President, The Cleveland Railway Company; res., 13705 McElhatten Ave., Cleveland, Ohio.

MOORE, MAURICE ARTHUR, Inspector of Electrical Materials, Bureau of Engineering Navy Dept.; 600 Terminal Annex Bldg., Philadelphia, Pa.

MUMMA, ROBERT W., Foreman, Electrical Construction, H. C. Felver, Pottsville; res., 20 N. 4th St., Steelton, Pa.

MURAMOTO, DAVID KITARO, 747 E. 36th St., Chicago, Ill.

NAGEL, HARRY L., Sales Correspondent, Wagner Electric Mfg. Company, 6400 Plymouth Ave., St. Louis, Mo.

NANEY, EDMUND PAUL, Construction Superintendent, Interstate Power Company, McGregor, Iowa.

NEAL, ALBERT G., Assistant Manager, Fitchburg Gas & Electric Light Company, 537 Main St., Fitchburg, Mass.

*NELSON, ARTHUR REYNOLD, Cadet Engineer, Public Service Electric Company of N. J., Camden; res., 228 Christiana St., Brooklawn, N. J.

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*NEWELL, NORMAN ALBERT, Telephone Engineer, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.; res., 87 Palisade Ave., West Hoboken, N. J.

NEWTON, ROBERT KEITH, Small Motor Section, Sales Dept., Wagner Electric Mfg. Company; res., 5240 Paulina Place, St. Louis, Mo.

*NORTHROP, BURDETTE K., Instructor in Electrical Engineering, Cornell University; res., 209 College Ave., Ithaca, N Y.

OKTAY, SULEIMAN T., Meter Tester, Northern Ohio Traction & Light Company, Terminal Bldg., Akron, Ohio.

OPPERMANN, RICHARD HERBERT, Electrical Tester, Philadelphia Electric Company, Philadelphia; res., 234 S. 5th St., Darby, Penn.

*OSBURN, ORREN EDGAR, Student Engineer, General Electric Company; res., 153 Barrett St., Schenectady, N. Y.

O'SULLIVAN, ROBERT JOHN, Telephone Operator, Avalon Telephone Company, Ltd., St. Johns, Newfoundland.

PADUAN, NICHOLAS, Electrician, Copper Range Railroad Company, Houghton, Mich.

*PAI, MING HSING, Student Engineer, General Electric Company, Schenectady, N. Y.; 1 Pau Zen Lee, Pau Tong Road, Shanghai, China.

*PALMER, RAYMOND J., Electrician, Oxford, Mich.

PARKER, HARRY ANGUS, Manager, Nelson Office, Canadian General Electric Company, Ltd., Nelson, B. C.

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*PETERS, LEO JAMES, Instructor in Electrical Engineering, University of Wisconsin, Madison, Wis.

PETTY, JAMES HOWARD, Shop Foreman, Cabin Creek Consolidated Coal Company, Kayford, W. Va.

POOLE, FOSTER MALIC, Engineer, St. Louis Electric Bridge Company, 3725 N. Broadway, St. Louis, Mo.; res., 226 Fourth St., Edwardsville, Ill.

POWERS, CHARLES FRANCIS, Correspondent, Westinghouse Elec. & Mfg. Company, E. Pittsburgh; res., 414 Biddle Ave., Wilkinsburg, Pa.

PRADHAN, WAMAN BHASKER, Construction Engineering Dept., General Electric Company; res., 740 Eastern Avenue, Schenectady, N. Y.

QUIGLEY, ALEXANDER, Operator in charge, Toronto Station, Hydro Electric Power Commission, Terminal Station, 6 Strachan Ave., Toronto, Ont., Canada.

RAY, GEORGE HARVEY, Switchboard Engineer, Westinghouse Electric & Mfg. Company, 1906 Pine St., St. Louis, Mo.

*RICE, GEORGE RUSSELL, Engineering Dept., Puget Sound Power & Light Company, Tacoma; res., Puyallup, Wash.

ROBERTS DONALD E., X-Ray Technician, U. S. Public Health Service, Waukesha, Wis.

ROBINEAU, RAPHAEL HENRY, Electrical Engineer, Chilian Electric Tramway & Light Company, Ltd., Casilla 1557, Santiago, Chile, S. A.

ROCK, GEORGE D., Instructor in Electrical Engineering, Catholic University of America, Washington, D. C.

*RODE, NORMAN FREDERICK, 3rd Assistant Engineer, Sinclair Navigation Company, Chronical Bldg., Houston, Texas; res., 1821 Audubon St., New Orleans, La.

ROEHRICH, WILLIAM H., Proprietor, Utility Battery Service; 665 Northampton St., Easton, Pa.

*ROHRECKER, LOUIS ROBERT, Assistant Engineer, United Electric Light & Power Company, 15th St. Irving Place; res., 2147 Blackrock Ave., New York, N. Y.

*ROSE, BERNARD, Electrical Engineer, 113 Belmont Ave., Brooklyn, N. Y.

*ROSS, JOHN L., Load Dispatcher, Pittsburgh Railways, Pittsburgh; res., 1420 Elm St., Wilkinsburg, Pa.

*RUPP, WELLINGTON, Assistant Engineer, Dept. of Public Works of Washington, Capitol Bldg.; res., 205 E. 10th, Olympia, Wash.

*RYAN, PHILIP, Electrical Engineer, Cutler-Hammer Mfg. Company; res., 174 13th St., Milwaukee, Wis.

*RYDER, MILTON PHILLIPS, Student, California Institute of Technology; Operator, Southern California Edison Company; res., 137 S. Los Robles Ave., Pasadena, Calif.

*SAHLMANN, FRANK LOUIS, Testing Dept., General Electric Company; res., 101 6th Ave., Schenectady, N. Y.

SAYRE, WILLIAM LOUIS, Partner, The Sayre-Level Radio Company, 905 Filbert St., Philadelphia, Pa.

SCHNEIDER, WILLIAM LEWIS, Electrician, Navy Yard, Building No. 41, Brooklyn; res., 310 Freeman Ave., Long Island City, N. Y.

SCHRADER, FRANK JOSEPH, Erecting Dept., Iowa Railway & Light Company, Cedar Rapids, Iowa.

SEAL, TONG GARRETT, Superintendent of Distribution, Virginia-Western Power Company, Buena Vista, Va.

*SEARLE, WILLIAM J., JR., Chief Locator, Underground Dept., The Philadelphia Electric Company, Philadelphia; res., 806 E Glenn Terrace, Chester, Pa.

*SELLKE, FRED A., Assistant Switchboard Operator, West Penn Power Company, New Kensington, Pa.

SELLMAN, ALBERT H., Assistant Electrical Engineer, Bureau of Standards, Washington, D. C.

SHUMAKER, RAYMOND LEE, Designer, Dayton Engineering Laboratories Company, Dayton; res., 668 S. Detroit St., Xenia, Ohio.

*SIDENFADEN, OSCAR LOUIS, Student Engineer, Testing Dept., General Electric Company; res., 1504 Union St., Schenectady, N. Y.

SLEEPER, HARVEY PRESCOTT, Relay Engineer, Supply Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh Pa.

*SMIDDY, HAROLD FRANCIS, Service Engineer, West Penn Power Company; res., 526 S. Graham St., Pittsburgh, E. E., Pa.

*SMITH, LANSING TAYLOR, JR., Office Engineer, Northern Division, Alabama Power Company, Huntsville, Ala.

SMITH, STANLEY, HOWARD, Toll Testboardman, The Pacific Tel. & Tel. Company; res., 4315 West Hinds St., Seattle, Wash.

SMITH, THOMAS IRA Electrical Engineer, Henningson Engineering Company, 12th & Harvey Sts.; res., 4336 Wakeley St., Omaha, Neb.

*SPENCE, PAYTON WESTBROOK, Long Line Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York; res., 54 Sedgwick Ave., Yonkers, N. Y.

SPOFFORTH, WALTER, Chief Engineer-Master Mechanic, Montgomery Ward & Company; res., 714 Hamline Ave. N., St. Paul, Minn.

SPRATLEY, JAMES BECKWITH, Telephone Engineer, Chesapeake & Potomac Telephone Company, Washington, D. C.; 202 38th St., Norfolk, Va.

STARBIRD, LEVI C., Instructor in Electrical Engineering, University of Arkansas; res., 426 Vandeventer Ave., Fayetteville, Ark.

*ST. CLAIR, WARD KENT, Student, Montana State College, Glasgow, Mont.

STEERUP, GODFREY, Research Chemist, Schweitzer & Conrad, Inc.; res., 2218 Sedgwick St., Chicago, Ill.

STEVERS, HAROLD D., Salesman, Electrical Engineers Equipment Company, 35 South Desplaines St., Chicago, Ill.

STEWART, GEORGE RAY, General Wire Chief, Illinois Central Railroad, 135 E. 11th Place, Chicago, Ill.

STILLWELL, WALTER I., Electrical Designer, Dwight P. Robinson & Company, Inc., Grand Central Palace, New York, N. Y.

*STOUT MELVILLE B., Assistant Electrical Engineer, Westinghouse Air Brake Co. Wilmerding; res., Woodruff St., Pittsburgh, Pa.

STRONG, JOHN S., Instructor in Electrical Engineering, University of Wisconsin, Madison, Wis.

*STRYKER, NORMAN RANSAVELL, Engineer, Transmission Dept., Western Electric Co., 463 West St., New York, N. Y.; res., 204 Jackson St., Trenton, N. J.

SULLIVAN, R. S., Research Engineer, North East Electric Company; res., 15 Orlando St., Rochester, N. Y.

SWAIN, EARL HAZZARD, Electrical Engineer, Stephen Sanford & Sons, Inc.; res., 15 Division St., Amsterdam, N. Y.

SWANEY, JAMES WILFRED, Second Engineer, Lake Coleridge Power Station, Lake Coleridge, N. Z.

*TANNER, ALTA ROY, Student Engineer, General Electric Company; res., 320 Ostrander Place, Schenectady, N. Y.

TAYLOR, CHARLES C., Transmission Tester, American Tel. & Tel. Company, 606 Telephone Bldg., Denver, Colo.

TAYLOR, JOSHUA WILLIAM, Electrical Superintendent, General Necessities Corp.; res., 4855 Linsdale Ave., Detroit, Mich.

THALHEIMER, ULRICH STEPHEN, Student Engineer, Pacific Tel. & Tel. Company; res., 1567 Jones St., San Francisco, Calif.

THATCHER, R. E., Superintendent, Service Dept., Puget Sound Power & Light Company, Electric Bldg., Seattle, Wash.

THOMSON, ARCHIBALD, Shift Engineer, Addington Substation, Lake Coleridge Hydro-Electric Scheme, Christchurch, N. Z.

*TOLLISON, PAUL LINDSY, Professor of Science & Coach, Piedmont Institute, Waycross, Ga.

TOPHAM, BERTRAM JOHN, Electrical Maintenance, Swift Canadian Company, Union Stock Yards; res., 134 Vine Ave., Toronto, Ont., Canada.

*TOUSSAINT, RICHARD PHILIP, Engineering Draftsman, New York Central Railroad, 466 Lexington Ave.; res., 3156 Hull Ave., New York, N. Y.

*TRANT, JAMES LEO, Engineer, Small Motor Dept., General Electric Company, Ft. Wayne; res., 438 S. Walnut St., Hartford City, Ind.

*TURNER, CLINTON H., Haverhill Street, North Reading, Mass.

*VAN NEST, PERCIVAL CHRISTIAN, Testing Dept., Public Service Company of Northern Illinois, 72 W. Adams St.; res., 5008 W. Erie St., Chicago, Ill.

*VAN VALKENBURG, KENNETH H., Electrical Designer, Electric Bond & Share Company, 71 Broadway, New York; res., 8509 107th St., Richmond Hill, N. Y.

VILLIERS, WILLIAM ROBERT, Electrical Foreman, Wilson-McGovern Company; res., 318 Logan Ave., Toronto, Ont., Canada.

VINCENT, FREDERICK JOHN, Testing Dept., Toronto Hydro-Electric System, 226 Yonge St., Toronto; Lansing, Ont., Canada.

VON NORMANN, ALFRED GEORGE, Testing Dept., General Electric Company; res., 24 Eagle St., Schenectady, N. Y.

WALL, JAMES J., Paper Mill Specialist, Milwaukee Office, General Electric Co., 430 Public Service Bldg., Milwaukee, Wis.

WALLACE, THOMAS ARTHUR, Sales Correspondent, Wagner Electric Mfg. Company; res., 3942 Folsom Ave., St. Louis, Mo.

*WALLS, HOY JAY, Instructor in Electrical Engineering, West Virginia University; res., 7 S. High St., Morgantown, W. Va.

*WALTON, ALLYN K., Operator, Heat Balance Board, Hell Gate Power Station, United Electric Light & Power Co., 134th St. & East River, New York, N. Y.

WAYTS, EDWARD, B., Assistant General Manager, Badger Electric Service Company; res., 314 S. Hamilton St., Madison, Wis.

WEBSTER, LOCKE EDWARD, Installation Foreman, Western Electric Co., Inc., 84 Marion St., Seattle, Wash.

WELLFORD, A. L., Jr., Engineering Dept., Appalachian Power Company, Bluefield, W. Va.

WELLINGTON, HUGO W. H., Electrical Technical Engineer, Edison Illuminating Company of Boston; res., 23 East St., Dorchester, Mass.

WHIPPLE, WILDER C., Foreman, Electrical Repair Shop, Puget Sound Power & Light Company, 1324 Western Ave., Seattle, Wash.

WHITE, CHARLES FRANK HARFORD, Cable Engineer, Western Electric Co., Ltd., N. Woolwich, London; res., 31 Beresford Road, Lowestoft, Eng.

*WHITE, RUSSELL GREY, Electrical Service Inspector, Bureau of Power & Light, City of Los Angeles; res., 1800 Hobart Blvd., Los Angeles, Calif.

WHITMAN, ALLEN LEE, Engineer, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.; Shippensburg, Pa.

WHITMORE, THOMAS, Central Office Repairman, The Home Tel. & Tel. Company; res. W. 819½ First Ave., Spokane, Wash.

WHITTON, WILLIAM H., General Wholesale Agent, New York Edison Company, 130 E. 15th St., New York, N. Y.

*WILCOXEN, MAX W., Electrical Draughtsman, The International Nickel Company; res., 615 2nd St., Huntington, W. Va.

*WILKINS, ROY T., Student Engineer, General Electric Company, 24 Baker St., Lynn, Mass.

WILLIAMS, LESTER W., Department Heed, Western Electric Company, Hawthorne Station, Chicago, Ill.

WILLIAMSON, ERROL THOMAS, Sales Agent, Power & Mining Dept., General Electric Company, Monadnock Block, Chicago, Ill.

WILLIS, OLO C., Chief Engineer, P. A. Geier Company; res., 647 E. 113th St., Cleveland, Ohio.

WILSON, ALBERT EDWARD, Electrical Engineering Dept., Hydro-Electric Power Commission of Ontario; res., 104 Hazelton Ave., Toronto, Ont., Canada.

WILSON, WILLIAM A., Chief Operator, Western Union Telegraph Company; res., 612 Cherry St., Bristol, Tenn.

WINGARD, OSCAR, Chief Draftsman, Bureau of Power & Light, City of Los Angeles, Public Service Bldg.; Loma Vista & Glendale Blvd., Los Angeles, Calif.

*WISE, RALEIGH JOHNSON, Night Automatic Chief, Western Union Telegraph Company; res., 94 Washington St., Atlanta, Ga.

*WOLKING, CLIFFORD GALE, Inspector, Elec. Installation, Hell Gate Power House, Westinghouse Elec. & Mfg. Co.; res., 470 E. 161st St., New York, N. Y.

*WOOD, CLAUDE OBERN, Electrical Engineer, Goodman Mfg. Company, Halsted & 48th Place, Chicago, Ill.

WOOSTER, LAWRENCE FISHER, Professor of Applied Electricity, Oregon Agricultural College, Mechanical Hall, Corvallis, Ore.

*WYMAN, LEE EDGAR, Student, School of Engineering of Milwaukee; res., 306 Lyon St., Milwaukee, Wis.

YAMADA, YASUTARO, Chief Electrical Engineer, Keihin Electric Power Co., 13-2 Chome, Kobikicho, Kyobashi, Tokyo, Japan.

*ZERBE, PARIS JOHN, Designer, Philadelphia Electric Company; res., 3827 N. Franklin St., Philadelphia, Pa.

*Formerly Enrolled Students.

Total 285.

ASSOCIATES REELECTED FEBRUARY 16, 1922

ALDER, GEORGE W., Consulting Engineer, Good Housekeeping Institute, 105 W. 39th St., New York, N. Y.

*BECK, CLIFFORD C., Assistant Chief Engineer, The Ohio Brass Company, Mansfield, Ohio.

BYRON, JOHN P., Engineer & Salesman, Hotel Wintonia, Seattle, Wash.

PAYNE, LEWIS, General Superintendent, Virginia-Western Power Company, Clifton Forge; res., 210 N. Maple Ave., Covington, Va.

PEARCE, JOHN HENRY, Designing Engineer, Skagit River Power Dept., City of Seattle, 110 Cherry St., Seattle, Wash.

STEIN, HERMAN K., Superintendent & Electrical Engineer, Genesee Light & Power Company; res., 212 State St., Batavia, N. Y.

MEMBERS ELECTED FEBRUARY 16, 1922

BOREL, ARNOLD, Director of Cables, Berthoud Borel Company, Cortaillod, Switzerland.

DALTON, WILLIAM HERBERT, Electrical Engineer & Manager, Dalton-Marsh Company, Danvers; res., 1 Devereux Ave., Salem, Mass.

DODD, HAROLD, Lieutenant-Commander, Navy Dept., Washington, D. C.; U. S. Naval Air Station, Pensacola, Fla.

GEENENS, LEO, Electrical Engineer, Hershey Corporation and Hershey Cuban Railway Co., Central Hershey, Province of Habana, Cuba.

HALLOCK, FLETCHER D., Textile Engineer, Westinghouse Electric & Mfg. Company, 10 High St., Boston; res., Riverbank Road, Cambridge, Mass.

HUNT, HENRY JAMES, Assistant Engineer, with Daniel W. Mead & C. V. Seastone, State Journal Bldg.; res., 2146 Keyes Ave., Madison, Wis.

JOHNSTON, J. MCLEAN, Power Engineer & General Purchasing Agent, Klots Throwing Co.; National Spun Silk Co., 440 4th Ave., New York; res., 624 Marlborough Road, Brooklyn, N. Y.

SMITH, THOMAS ARTHUR, Assistant Chief Electrical Engineer, The Havana Central Railroad Company, Central Station, Havana, Cuba.

SPIELMAN, MILTON H., Electrical Engineer, Domestic Electric Company, Cleveland, Ohio.

TOLTZ, MAX, Consulting Engineer, President, Toltz King & Day, Inc., 1410 Pioneer Bldg., St. Paul, Minn.

WRIGLEY, GEORGE, Electrical Engineer, J. E. Sirrine & Company, Greenville, S. C.

TRANSFERRED TO GRADE OF FELLOW FEBRUARY 16, 1922

BRIGHT, GRAHAM, Engineer-in-Charge, Mining Section, General Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

TRANSFERRED TO GRADE OF MEMBER FEBRUARY 16, 1922

FLOYD, F. N., Assistant, Electrical Engineering Div., Dwight P. Robinson & Co., Inc., New York, N. Y.
GOLDING, JOSEPH N., Vice-President & General Manager, Mailhouse & Golding Inc., New Haven, Conn.
LEHURAUX, LOUIS, International General Electric Co., Schenectady, N. Y.
MIRICK, CARLOS B., Vice-President, National Electrical Supply Co., Washington, D. C.
PEET, JAMES C., Professor of Electrical Engineering, College of Engineering of Newark Technical School, Newark, N. J.
SAUNDERS, LLEWELLYN, Partner, Saunders & Sorrell, Norfolk, Va.
SCHARNBERG, HERMAN J. B., General Superintendent, Palma Soriana Sugar Co., Oriente, Cuba.
STEWART, CHARLES C., Chief Electrical Engineer, Sinclair Refining Co., Chicago, Ill.
STORY, EDWARD C., Supervising Cost Engineer, with Dr. Thomas Conway, Jr., Allentown, Pa.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held January 9 and February 10, 1922, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

NORTON, WILLIAM J., Member of Firm, Norton, Bird & Whitman, Newark, N. J.

To Grade of Member

BOYRER, WILLIAM C., Electrical Engineer, Public Service Commission, New York, N. Y.
DILL, GEORGE C., Designing Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
HARSEIM, HENRY, W. V. Pangborne & Co., Philadelphia, Pa.
PRESCOTT, RICHARD D., Inspector General Tel. & Tel. Panama Government, Panama, R. P.
ROBERTS, DOUGLAS A., General Supt., Southern Illinois Railway & Power Co., Harrisburg, Ill.
STEIN, HERMAN K., Supt., & Electrical Engineer, Genesee Light & Power Co., Batavia, N. Y.
WEBB, LEWIS W., Master Electrician, U. S. Navy Yard, Norfolk, Va.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute, the list indicating the geographical district and Section in which the applicant is at present located. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1922.

Geographical District No. 1

Boston Section

Hunter, Cecil W., Boston, Mass.
Kalley, Oscar, Boston, Mass.
Pye, Harry A., Boston, Mass.

Connecticut Section

Cox, Grover A., New Haven, Conn.
Harris, Benjamin M., New Haven, Conn.
Mitchell, William H., New London, Conn.

Lynn Section

Hollnagel, Herbert P., Lynn, Mass.

Rochester Section

Payne, Burton R., Lancaster, N. Y.

Schenectady Section

Cogswell, Burnham, Schenectady, N. Y.
Ennis, Donald A., Schenectady, N. Y.
Geue, John E., Schenectady, N. Y.
Saupe, William E., Schenectady, N. Y.

Syracuse Section

Connell, Harvey F., (Member), Baldwinsville, N. Y.
Jones, David A., Syracuse, N. Y.
Williams, Edward Q., Syracuse, N. Y.

Non-Section Territory

Loftus, Peter F., Ogdensburg, N. Y.
Total 16

Geographical District No. 2

Akron Section

Cipperley, Ian, Akron, Ohio

Baltimore Section

Adams, Robert L., Baltimore, Md.
Brittingham, Henry L., Baltimore, Md.
Nelson, Peter R., Baltimore, Md.

Cleveland Section

Mussen, William, Cleveland, Ohio
Wilson, Herbert W., Cleveland, Ohio

Lehigh Valley Section

Duncan, Hamilton A., Hauto, Pa.

Philadelphia Section

Cleveland, Francis D., Jr., Philadelphia, Pa.
Donnelly, Joseph B., Philadelphia, Pa.
Elgin, Charles P., Princeton, N. J.
Griffith, Charles, Philadelphia, Pa.
Hoyt, Fanning O., Philadelphia, Pa.
MacMichael, Hugh N., Germantown, Pa.

Pittsburgh Section

Kay, Thomas, Washington, Pa.
Skooglund, Carl M., Pittsburgh, Pa.
Tjiattas, Anastassios C., Pittsburgh, Pa.

Washington, D. C., Section

Blinston, Chester A., Washington, D. C.

Non-Section Territory

Hollar, W. Carter, Shippensburg, Pa.
Webbe, Harold W., (Fellow), Columbus, Ohio
Total 19

Geographical District No. 3

New York Section

Anderson, Raymond W., New York, N. Y.
Bagg, Raymond J., Brooklyn, N. Y.
Bartlett, Wallace A., New York, N. Y.
Barton, Henry A., New York, N. Y.
Baruch, Milton S., New York, N. Y.
Bogart, George H., New York, N. Y.
Charlesworth, Harry P., (Member), New York, N. Y.
Cheston, Albert D., Hoboken, N. J.
Cooley, Elihu H., New York, N. Y.
Crosby, Halsey E., New York, N. Y.
Cully, William L., New York, N. Y.
Curtis, George S., Paterson, N. J.
Davis, James L., New York, N. Y.
De Hunzu, Frank, New York, N. Y.
Despres, Joseph A., New York, N. Y.
Duehne, Herman, Jr., New York, N. Y.
Eaves, Augustus J., New York, N. Y.
Eddy, Herbert G., New York, N. Y.
Ellsworth, William C., New York, N. Y.
Evans, Clair O., (Member), New York, N. Y.
Favaro, Thomas, Jersey City, N. J.
Fear, Harold J., Hoboken, N. J.
Finch, William G. H., New York, N. Y.
Foster, William C., Newark, N. J.
Gerdin, Olaf G., Floral Park, L. I., N. Y.
Goodman, John M., New York, N. Y.
Griffin, Charles D., Mt. Vernon, N. Y.
Haggerty, David D., New York, N. Y.
Harlow, John B., (Member), New York, N. Y.
Hewett, Roger S., Long Island City, N. Y.
Hewitt, Ernest W., New York, N. Y.
Heyden, Adolf O., New York, N. Y.
Hoffman, Henry L., New York, N. Y.
Holway, Edward, Jr., New York, N. Y.
Howe, Kassan, Mt. Vernon, N. Y.
Hummler, August, Brooklyn, N. Y.
Hunt, Arthur E., New York, N. Y.
Inada, Sannosuke, New York, N. Y.
Ingalls, Ross D., Elizabeth, N. J.
Inglis, Alfred H., New York, N. Y.
Johnson, Edward J., New York, N. Y.
Kennedy, William F., Long Island City, N. Y.
Kinlock, William H., New York, N. Y.
Knoepke, William L., New York, N. Y.
Kuhn, George W., (Member), New York, N. Y.
La Due, William A., (Member), Jersey City, N. J.
Larlee, Herman A., (Member), New York, N. Y.
Leavens, Eric, New York, N. Y.
Leuvelink, Bernard, New York, N. Y.
Lewis, Charles H., Jersey City, N. J.
Lyons, George E., Long Island City, N. Y.
McCarty, George M., New York, N. Y.
McKinley, Henry C., New York, N. Y.
Meyerowitz, Paul R., New York, N. Y.
Milne, Irving J., Long Island City, N. Y.
Molina, Edward C., (Member), New York, N. Y.
Muller, John H., Jr., New York, N. Y.
Oliver, Robert B., New York, N. Y.
O'Roark, Lauren S., New York, N. Y.
Parker, George B., New York, N. Y.
Porter, Seton, (Member), New York, N. Y.
Redd, John C., New York, N. Y.
Richards, William L., New York, N. Y.
Roberts, Le Roy C., New York, N. Y.
Rogers, Hurley T., Long Island City, N. Y.
Rubyor, Harold E., New York, N. Y.
Rudisill, Wesley H., New Brighton, S. I., N. Y.
Sanders, Joseph B., East Orange, N. J.
Schwab, Thomas C., Long Island City, N. Y.
Stacy, Leland J., (Member), New York, N. Y.
Stellger, Henry J., Hoboken, N. J.
Stephens, Charles E., (Member), New York, N. Y.
Stoskopf, Louis N., New York, N. Y.
Stott, Robert A., (Member), New York, N. Y.
Taggart, Dawson M., (Member), New York, N. Y.
Tallman, William J., New York, N. Y.
Trumbull, Arthur J., Brooklyn, N. Y.
Van Duesen, George L., Camp Alfred Vail, N. J.
Van Etsen, Leo A., New York, N. Y.
Waechter, Frederick A., Passaic, N. J.
Ward, Ferdinand J., Jr., New York, N. Y.
Wheeler, Evan R., New York, N. Y.
Wilcox, Edgar S., New York, N. Y.
Williams, Joseph, New York, N. Y.
Willis, Frederick C., New York N. Y.
Wolfe, Lester, New York, N. Y.
Young, Fred A., Astoria, L. I., N. Y.
Zeiss, Anthony, New York, N. Y.
Ziegler, Adolph L., New York, N. Y.

Non-Section Territory

Cardenas, Armando, Monterey, Mexico
Total 90

Geographical District No. 4

Non-Section Territory

Ayo, Essie R., Charlotte, N. C.
Berry, Joel H., Norfolk, Va.
Gassaway, Crosby M., Sylvan, N. C.
Orr, Claudius A., (Member), Mayfield, Ky.
Richardson, H. Leonard, Birmingham, Ala.
Total 5

Geographical District No. 5

Chicago Section

Carper, Chester O., Chicago, Ill.
Carr, John O., Chicago, Ill.
Garrett, Anthony M., Chicago, Ill.
Grant, Richard J., Evanston, Ill.
Moore, Daniel E., Chicago, Ill.
Quayle, Frederick R., (Member), Chicago, Ill.
Roberts, Irving T. (Member), Chicago, Ill.
Seyferlich, Walter M., Chicago, Ill.

Detroit-Ann Arbor Section

Miller, Andrew L., Ann Arbor, Mich.
Widmer, Jules A., (Member), Detroit, Mich.

Ft. Wayne Section

George, Earl B., Ft. Wayne, Ind.
Shaefer, Earl A., Ft. Wayne, Ind.

Indianapolis-Lafayette Section

Holmes, Frederick, Lafayette, Ind.
McDermott, John A., (Member), Indianapolis, Ind.
Pavey, Francis L., Lafayette, Ind.
Pyle, William F., Lafayette, Ind.

Milwaukee Section

Eells, M. Merwin, Milwaukee, Wis.
Love, John S., Milwaukee, Wis.
Onarheim, James I., W. Allis, Wis.
Schumacker, William C., Milwaukee, Wis.
Siegl, A., Wauwatosa, Wis.

Urbana Section

Bullions, Cornelius S., Urbana, Ill.
Total 22

Geographical District No. 6

Denver Section

Anderson, Albert S., Denver, Colo.
Green, Walter B., Denver, Colo.
McCabe, J. H., Denver, Colo.
McCallum, Alexander F., Denver, Colo.
Nelson, Walter K., Boulder, Colo.
Slattery, Thomas F., Denver, Colo.

Minneapolis Section

Anderson, Joseph W., Minneapolis, Minn.
Bade, Courtland W., Minneapolis, Minn.
Kingsley, Norman W., Minneapolis, Minn.
Meyer, Hans J., Minneapolis, Minn.
Taylor, John D., Minneapolis, Minn.

Non-Section Territory

Burgess, G. Harold, Duluth, Minn.
Total 12

Geographical District No. 7

Kansas City Section

Shutt, Edwin H., Kansas City, Mo.
Zworykin, Vladimir K., (Fellow), Kansas City, Mo.

St. Louis Section

Brown, William J., St. Louis, Mo.
Morris, Rollo C., St. Louis, Mo.
Samson, Fred W., St. Louis, Mo.

Non-Section Territory

Holmes, Jack, Gibson, New Mex.
Total 6

Geographical District No. 8

Los Angeles Section

Hancock, Winfield Scott, Huntington Park, Calif.

San Francisco Section

Pardee, Starr C., San Francisco, Cal.

Non-Section Territory

La Montagne, Leslie H., Taft, Calif.
Reich, Henry L., Manila, P. I.
Wilkie, David F., Temple, Ariz.
Total 5

Geographical District No. 9

Seattle Section

Blake, Buel B., Seattle, Wash.
Gravell, Adolph J., Wenatchee, Wash.
Haakons, Hugo R., Seattle, Wash.
Watkins, John W., Seattle, Wash.

Utah Section

Osborne, Thomas A., Salt Lake City, Utah
Total 5

Geographical District No. 10

Toronto Section

Brian, Alfred, (Member), Cobalt, Ont.
Brace, George A., Toronto, Ont.
Brake, Reginald L., Hamilton, Ont.
MacDonald, Roderick N., Port Dahousie, Ont.

Vancouver Section

Mainwaring, William C., Vancouver, B. C.
Sendey, Albert C. G., Vancouver, B. C.
Total 6

Total Applications Received 186

FOREIGN

Santiago Section

Doxey, William, Taltal, Chile, S. A.
de Mello, Eustaquio G., Brazil, S. A.
Ghose, Kashi P., (Member), Calcutta, India
Huntress, Frederick A., Rio de Janeiro, Brazil, S. A.
McCabe, William L., Honolulu, T. H.
Peck, Louis T., (Member), Buenos Aires, Argentine, S. A.
Shimidzu, Yoshichiro, Tokyo, Japan
Total 7

STUDENTS ENROLLED FEBRUARY 16, 1922

14541 Donnelly, Walter L., Lowell Inst. School for Industrial Foreman
14542 Hafel, Clare P., University of Notre Dame
14543 Pugh, Morton G., Ohio Northern Univ.
14544 Teveliet, Rudolph, New York Elec. School
14545 Lodas, Frank, New York Electrical School
14546 Koehler, Oscar H., University of Illinois
14547 Prideaux, Gwilym F., Univ. of Wisconsin
14548 Leighton, Russell S., University of Maine
14549 Matz, Charles A., New York Elec. School
14550 Hallock, Arthur, New York Elec. School
14551 Fryer, Baron P., New York Elec. School
14552 Studer, Clarence R., State College of Wash.
14553 Ishiyama, Eiitsu, State College of Wash.
14554 Leahy, Edwin J., State College of Wash.
14555 Powers, Ralla E., State College of Wash.
14556 Hubbard, Eben R., Mass. Inst. of Tech.
14557 Dallye, Frederick R., Mass. Inst. of Tech.
14558 Bradway, Earl E., Purdue University
14559 Hurst, Robert O., Purdue University
14560 Flynn, William P., University of Wisconsin
14561 Armstrong, Hoyt, Clemson Agri. Coll.
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14565 Alger, Prentiss B., Mass. Institute of Tech.
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14568 Yell, Percival B., New York Elec. School
14569 Sherman, Russel E., N. Y. Elec. School
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14571 Eaton, Reginald O., Case School of Applied Science
14572 Cabalek, Edward L., Case School of Applied Science
14573 McCoy, Robert L., Case School of App. Sci.
14574 Morris, Robert M., Case School of Applied Science
14575 Hauf, Joseph C., Jr., Johns Hopkins Univ.
14576 Vogel, Henry H., Johns Hopkins Univ.
14577 Schuchts, David E., Johns Hopkins Univ.
14578 Kinnamon, Lester B., Johns Hopkins Univ.
14579 Gallotte, Willard A., Worcester Poly. Inst.
14580 Ross, George O., Tri-State Coll. of Eng.
14581 Johnson, Ernest E., State College of Wash.
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14583 Palmer, Elsa, Swarthmore College
14584 Schulz, W. A., Swarthmore College
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14586 Levenmann, Henry W., N. Y. Elec. School
14587 De Lucia, Anthony, N. Y. Elec. School
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14589 Carlberg, Eric, Jr., New York Elec. School
14590 Kidd, George H., New York Elec. School
14591 Norton, Edward L., Mass Inst. of Tech.
14592 Leake, Robert A., University of Alabama
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14594 Egan, George R., University of Nevada
14595 Brown, Harold E., Rensselaer Poly. Inst.
14596 Strang, Harold E., Rensselaer Poly. Inst.
14597 Buxton, Stuart C., Rensselaer Poly. Inst.
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14601 Hill, Harry R., Rensselaer Poly. Inst.
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14642 Brody, Edward, Cooper Union
14643 Bruns, William H., Jr., Cooper Union
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14683 Shipe, John A., School of Engg. of Mil.
14684 Banks, Henry R., School of Engg. of Mil.
14685 Fuller, Huber E., School of Engg. of Mil.
14686 Velasco, Jose, Jr., School of Engg. of Mil..
14687 Schibursky, Leslie V., School of Engg. of Milwaukee
14688 Tholstrup, Henry, School of Engg. of Mil.
14689 Thompson, George W., School of Engg. of Milwaukee
14690 Breimo, Oscar L., School of Engg. of Mil.

14691 Disch, Milton A., School of Engg. of Mil.
14692 Vasconcelos, Joaquin M., School of Engg. of Milwaukee
14693 Rogers, H. Burrows, School of Engg. of Mil.
14694 McMahon, Alvin M., School of Engg. of Mil.
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14699 Crowley, John J., Chicago Technical Coll.
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14702 Randall, Theron C., Clarkson Coll. of Tech.
14703 Burrill, Charles M., University of Minn.
14704 Connell, Lawrence H., Mass. Inst. of Tech.
14705 Connelly, Robert G., Stanford University
14706 Bertrand, DeWitt C., Stanford University
14707 Small, Edwin W., Stanford University
14708 James, Arthur G., Stanford University
14709 Payne, George H., Stanford University
14710 Miller, Walter G., Stanford University
14711 Lamb, George B., Mass. Inst. of Tech.
14712 Tomlinson, Henry R., Mass. Inst. of Tech.
14713 Royal, Edward, Mass. Inst. of Tech.
14714 Schultz, Sol Eli, Drexel Institute
14715 Stewart, Douglas C., Mass. Inst. of Tech.
14716 Spurlock, Hugh G., Alabama Poly. Inst.
14717 Taylor, John O., Alabama Poly. Inst.
14718 Lynch, Charles B., Alabama Poly. Inst.
14719 Turner, Morton V., Alabama Poly. Inst.
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14743 Phillips, Albert, Cooper Union
14744 Pshedezky, Paul, Cooper Union
14745 Rodd, Clifford A., Cooper Union
14746 Ross, John E., Cooper Union
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14748 Williams, Arthur, Cooper Union
14749 Malone, John D., Jr., University of Ala.
14750 Thor, Berg V., Armour Inst. of Tech.
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14752 Horgan, Francis J., Mass. Inst. of Tech.
14753 Callahan, Martin E., Jr. Univ. of Utah
14754 Herdti, G. D., University of Utah
14755 Howarth, G. Alvin, University of Utah
14756 Kajer, Homo J., University of Utah
14757 Lee, Karl C., University of Utah
14758 Littlefield, James C., University of Utah
14759 Mahoney, Cornelius P., Jr., Univ. of Utah
14760 Plates, Chris S., University of Utah
14761 Robbins, George W., University of Utah
14762 Ross, Marion S., University of Utah
14763 Webb, Spencer E., University of Utah
14764 Williams, David G., University of Utah
14765 Wolcott, Perry R., University of Utah
14766 Woodbury, Eugene, University of Utah

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A complete list of the 42 Sections and the 67 Student Branches of the Institute, with the names of the chairmen and secretaries, may be found in the January issue and will be published again in the June issue.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGS AND OTHER TRADE PUBLICATIONS

Mailed to interested readers by issuing companies.

Polyphase Motors.—Bulletin 284, 16 pp. B. F. Sturtevant Co., Hyde Park, Mass.

Electrically Operated Valve Control.—A series of bulletins describing electrical control of valves for waterworks and steam plants. Payne Dean Ltd., 103 Park Ave., New York.

Meter Service Switches.—Circular 4484. For use by central stations in supplying service to homes and apartment houses. Employed in connection with any standard meter, or independently, if desired. Westinghouse Elec. & Mfg. Co., East Pittsburgh.

Pulverized Fuel Systems. Catalog No. 12, 48 pp. Describing the Quigley system of preparation, transportation and burning of pulverized fuel, and its application in various industries. Emphasis is laid upon the method employed to properly prepare and burn the powdered coal. Hardinge Company Inc., 120 Broadway, New York.

Tachometer.—Bulletin describing the Hasler-Tel Speed Indicator. Hasler-Tel Company, 461 Eighth Ave., New York.

Water Tube Boilers.—Catalog No. 63, 154 pp., cloth bound. In addition to data on the Edge Moore boiler, includes information on baffling and stokers, the properties of fuels, proportioning of chimneys, and other data in regard to boilers and their operation. Edge Moor Iron Co., Edge Moor, Del.

Radio Telegraph and Telephone.—Catalog, 208 pages, describing wireless equipment and accessories. Manhattan Electrical Supply Co., 17 Park Place, New York.

Time Switch.—Folder, describing Barnes Self-Winding Time Switch. J. O. Morris, Agent, 1270 Broadway, New York.

Small Motors.—Booklet, 44 pp., "Popular Motor Mechanics," illustrating practical uses for small motors, and distributed by this firm in their "over the counter" merchandising campaign. Westinghouse Elec. & Mfg. Co., East Pittsburgh.

Exhaust Fans.—Bulletin 1, 12 pp. Describing "Four Leaf Clover" exhaust fans for vertical installations. Centrifugal Fan Co., 15 Seventeenth St., Newark, N. J.

Motor Starter.—Bulletin 101, "Starting Small A-C. Motors." Describing the Monitor "Thermaload Starter" for which patents are pending. Monitor Controller Co., Baltimore, Md.

Industrial Motors.—Bulletins. No. 132, Elevators. No. 133, Pumps. No. 212, A-C., Squirrel Cage Type. No. 215, D-C. Motors and Generators. No. 301, Printing Press. No. 570, Polishing and Grinding, including accessory equipment. Roth Bros. & Co., Chicago.

Electricity in the Iron & Steel Industry.—Catalog, 242 pp. In German. Allgemeine Elektricitäts-Gesellschaft, Berlin NW., Germany.

Water Tube Boiler.—Bulletin 7. Describes the latest development of the "Wickes" horizontal, water tube boiler. Wickes Boiler Co., Saginaw, Mich.

Fuses and Fittings.—Discount and condensed catalog sheets. An arrangement whereby all products, prices and discounts may be ascertained from a 4-page bulletin, obviating reference to catalog. Killark Electric Mfg. Co., St. Louis, Mo.

Insulated Wire.—Bulletin, 16 pp. "Hazard Keystone Wire," for railroad signaling. Construction and tests are described, as well as common failures of insulated wires. Hazard Manufacturing Co., Wilkes-Barre, Pa.

Magnet Wire.—Catalog, "Acme Wire Products," describing magnet wire and coil windings manufactured by the Acme Wire Company, New Haven, Conn.

Motors, Generators.—Catalog 246, 54 pp. Describing "Sturtevant" motors, generators, turbine-generator sets, blowers, heaters, etc. B. F. Sturtevant Co., Hyde Park, Mass.

Instruments.—Bulletin 122. Describing the use of graphic instruments in industrial plants. The Esterline Co., Indianapolis, Ind.

Wire for Radio Stations.—Leaflet describing advantages of "Copperweld" wire for aerials, leads and feeder wires and ground connections and rods. Copper Clad Steel Co., Rankin, Pa.

NEW APPARATUS AND METHODS

Oil Circuit Breaker.—Type D-22. A high interrupting capacity switch of common frame and construction, some of the features of which are exceptionally strong tank-per-pole construction; each tank rigidly supported at four points on the frame; extending web on frame, reinforcing upper part of tanks; rigid frame construction, insuring contact alignment. High speed operation is obtained through use of light steel mechanism assisted by accelerating springs placed on each brush rod. Arcing tips are standard equipment on both stationary and movable contact members. High-glazed, wet-process porcelains provide ample insulation for current-carrying members. Type D-22 is furnished in usual standard arrangements for either hand or electrical operation, for sizes up to and including 1200 amperes for 15,000 volt service. Rating 2000 amperes at 15,000 volts. Condit Electrical Mfg. Co., Boston 27, Mass.

Electric Drill-Grinder.—A portable electric combination drill and grinder, with slow and high speed. Weight 18 pounds. Drilling capacity of ⅛″ to ⅝″ in steel, and when used with grinding attachment carries a 6″ wheel. Motor develops about one-half h. p. under load. Wodack Electric Tool Corp., Chicago.

MISCELLANEOUS

Roller-Smith Company.—Electrical instruments and circuit-breakers, New York. Pendleton E. Lehde, 609 Whitney Central Building, New Orleans, La., has been appointed special representative to handle this company's line in Louisiana and the southern part of Mississippi.

Wilson Welder & Metals Co., Inc., New York.—R. L. White has been appointed district manager in charge of the Detroit Office, 809 Kresge Building, Detroit, Mich.

The Allen-Bradley Company,—Electrical control apparatus, Milwaukee. This firm is now represented in Baltimore by Harry M. Wood.

The Morganite Brush Co., Inc.—New York. The Special Service Sales Co., 502 Delta Building, Los Angeles, has been appointed agent for Southern California.

Corliss Carbon Co., Bradford, Pa.—A. B. Holcomb has been appointed District Manager of the Pittsburgh office. Previously Mr. Holcomb was engaged in consulting and sales engineering in the Pittsburgh and Youngstown districts.

Henry D. Sears.—General Sales Agent for Weber Wiring Devices, Boston. A sales office in New York, at 342 Madison Avenue, has been opened in charge of Henry E. Nickerson, for the past eleven years New England representative.